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A DEMONSTRATION AND EVALUATION OF THE UTILIZATION OF

SIDE LOOKING AIRBORNE RADAR FOR MILITARY TERRAIN ANALYSIS

1 October 1975

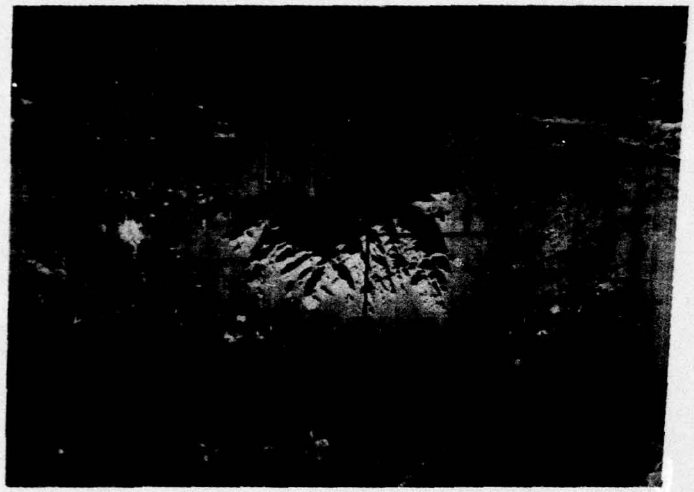
Approved for public release; distribution unlimited.

U.S. ARMY ENGINEER

TOPOGRAPHIC LABORATORIES

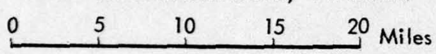
FORT BELVOIR, VA 22060

Elevation Measurement

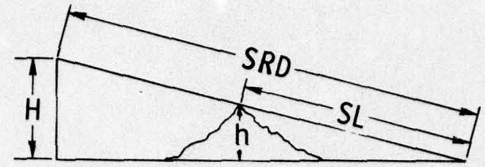


Near Range

White Tank Mountains, Arizona



AN/APS-94D
X-Band

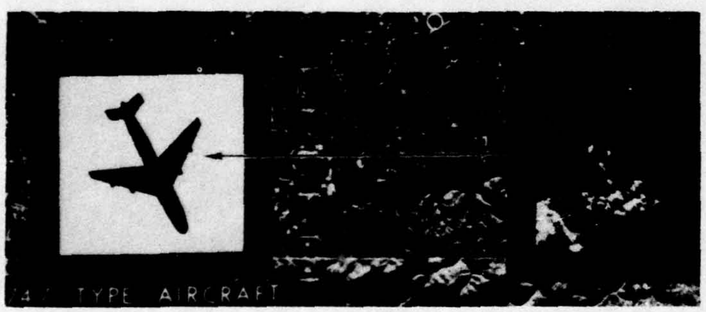


Ground Elevation = 1120'
H = Altitude of Plane Above Ground (9380')
SL = Shadow Length Behind Mountain (35,400')
SRD = Slant Range Distance to End of Shadow (114,600')
h = Height of Mountain Above Ground Level

By Similar Triangles, $h = H \cdot SL/SRD$
$h = 2897'$

Calculated Mt. Elev. = h (2897') + Ground Elev. (1120')
Calculated Mountain Elevation = 4017' (Actual ≈ 4020')

Ground Measurement (at 12 x Magnification)



AN/UPD-4

Aircraft Type: Large Jet Transport
Length Measured = 236' (Actual = 231')
Wingspan Measured = 193.5' (Actual = 196')

Goodyear Aerospace, Arizona Division

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Side looking airborne radar (SLAR) imagery acquired in diverse terrains and environments, was studied to demonstrate its value in military tactical terrain analysis. Capabilities unique to SLAR, such as all-weather and day or night image acquisition, are highlighted. In addition, other capabilities and limitations are also stressed to permit the utilization of SLAR with other sensors for maximum data retrieval. Imagery studied was selected on the basis of geographic location and data content, not system characteristics, and estimates are made of the → OVER

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improved data content that could be realized by modification of system parameters. By using a broader range of the electro-magnetic spectrum than most sensors and by operating under many controllable parameters, the appropriate radar system and system configuration can be selected for any mission by the user to realize maximum target information.

A DEMONSTRATION AND EVALUATION OF THE UTILIZATION OF SIDE LOOKING AIRBORNE RADAR FOR MILITARY TERRAIN ANALYSIS

ETL Report-0023

1 October 1975

Louis F. Dellwig, Bradford C. Hanson
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Paul L. Hulen, James R. McCauley
Richard K. Moore

Funded under Contract DAAG 02-75-C-0145 by the
U. S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

PREFACE

Since the organization of the Remote Sensing Laboratory at the University of Kansas in 1964 we have consistently strived to develop an understanding of the relationship between radar system and terrain parameters and the importance of each in the determination of the recorded return signal, always with the ultimate hope of providing the potential user with sufficient information to determine the value of SLAR for his particular discipline. However, we would be guilty of gross negligence if we implied that we alone have been responsible for the tremendous advances made in the utilization of SLAR in terrain analysis as presented in this document. The efforts of investigators, too numerous to mention, over a little more than a decade hopefully are acknowledged, at least to some degree, in this demonstration.

This document itself results from cooperation and help of numerous individuals not acknowledged in the list of authors, but without whose contribution it could not have been successfully completed. Headed by Mr. Bernard B. Scheps, Dr. Kenneth R. Kothe, Mr. Barry Shelkin and Major Phillip Wheeler critically, carefully and helpfully evaluated the manuscript at several stages and offered advice and suggestions which resulted in the development of the format which follows and effectively presents the case for radar as a tool for tactical military terrain analysis.

Funding was through the U. S. Army Engineer Topographic Laboratories, to which we offer our sincere thanks for the opportunity to demonstrate in one concise volume the capability of a remote sensing system with which we have worked for more than ten years.

To Ron Gelnett and Jim Lightcap of Motorola Aerial Remote Sensing, Inc. our deep appreciation for conducting at no cost multiple-look flights over Phoenix, at our request, and to Hugh Rydstrom and George La Prade of Goodyear Aerospace, Arizona Division, for making available file material and imagery which has been invaluable in the preparation of this document.

ABSTRACT

Side looking airborne radar (SLAR) imagery acquired in diverse terrains and environments, was studied to demonstrate its value in military tactical terrain analysis. Capabilities unique to SLAR, such as all-weather and day or night image acquisition, are highlighted. In addition, other capabilities and limitations are also stressed to permit the utilization of SLAR with other sensors for maximum data retrieval. Imagery studied was selected on the basis of geographic location and data content, not system characteristics, and estimates are made of the improved data content that could be realized by modification of system parameters. By using a broader range of the electro-magnetic spectrum than most sensors and by operating under many controllable parameters, the appropriate radar system and system configuration can be selected for any mission by the user to realize maximum target information.

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INTRODUCTION

Objective

This report is designed to demonstrate through analysis of imagery in a diversity of terrains, the value of utilization of side looking airborne radar (SLAR) in military tactical terrain analysis. It presents, in concise form, material which defines many of the capabilities but comes nowhere near exhausting them. The objective is to give the reader the essence of this capability in the first thirty-one pages and the details which he may desire in the appendices.

Purpose

In light of previously established capabilities (some unique) of radar for terrain analysis*, this demonstration was designed to illustrate in one report the value and importance of utilization of SLAR for tactical military terrain analysis. It is not intended that SLAR be presented as a panacea for all terrain analysis. A knowledge of both the capabilities and limitations of such systems permits their utilization along with other sensors for acquisition of maximum data. But it is recognized that SLAR stands alone as a day or night near all-weather sensor and, under such conditions, might be a singular or primary source of data. It is the purpose of this report to highlight these radar attributes and their military implications for tactical terrain analysis as representative of a now large, growing and scattered literature.**

Scope

The selection of areas for analysis in the demonstrations which follow was based on geographic location and the data content of the imagery rather than on the characteristics of the systems. Military operations are not confined to a particular terrain environment, the environment often being forced upon the military rather than being selected. Thus, the consideration of any sensor as a tool for

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* See Background, page 3.

** Dellwig, L.F., et. al., "Use of Radar Images in Terrain Analysis: An Annotated Bibliography, ETL Report 0024, CRES Technical Report 288-2, University of Kansas Center for Research, Inc., Lawrence, Kansas, October 1975.

military terrain analysis necessitates its being evaluated in a wide variety of terrains. As a result imagery utilized has been generated by a variety of systems with wide variations in system parameters. In each area evaluated, data content of the image generated by a particular system will be evaluated on the basis of the system's parameters. In addition, based on previous experience, an estimate will be made as to the degree to which data content can be refined or increased with modification in system parameters. Thus, the scope covers both the delimitation of some of the kinds of terrain data interpretable and the advantages of various radar system characteristics for maximizing certain kinds of data.

Organization

This report has been organized so as to be useful to a variety of readers. The first thirty-one pages contain the entire study content in summary form. The conclusions at the end of this main body of the report are the total conclusions drawn from all of the detailed work. The appendices provide detailed data regarding radar generally, interpretation factors and methods and the detailed analyses of each image selected for evaluation. Each appendix (A-F) includes more specific results and conclusions applicable to the image evaluated. Thus, the reader may read at any level of detail.

Approach

Following the selection of appropriate areas, analysts trained in interpretation of SLAR imagery evaluated the imagery for the revelation of data in the following broadly defined categories:

1. Construction Sites and Materials
2. Cover and Concealment
3. Cultural Features and Hard Targets
4. Hydrology
5. Lines of Communication
6. Soils and Soil Depth
7. Surface Configuration
8. Troop and Vehicle Movement

Emphasis in analysis and derivation of data relative to the above categories necessarily varied with terrain conditions. The interpreters previous knowledge of the area was limited to general information easily accessible to any investigator.

It must be understood that although radar senses different properties of the earth's surface, its vegetative cover, and the works of man than does the aerial camera; the interpreter of radar imagery is guided by the same principles of interpretation as is the interpreter of aerial photography. Neither the aerial photograph nor radar at K- and X-band frequencies (Figure 1) reveal any significant subsurface data; postulation of subsurface conditions is based on the interpreter's overall knowledge of the climatic, vegetative and topographic conditions of the particular region in which the image of the photograph is generated.

Background

Side-looking airborne radars (SLAR) were decisively documented as terrain reconnaissance tools in 1965 by the U.S. Army (GIMRADA) with the imaging of Darien Province, Panama, by the AN/APQ-97 radar on a YEA-3A platform. In this area of near-continuous cloud cover (Figure 2), a fifteen year effort to obtain complete photographic coverage had resulted in the acquisition of aerial photography over only 30 percent of the area. Employing the AN/APQ-97 radar system, the entire target area of 10,000 square miles was imaged four times in six days of operation, one complete coverage being obtained in four hours of flying time. Collecting interferometer data as well as imagery resulted not only in the collection of a considerable degree of topographic, hydrologic, geologic, vegetative and soil data which had never before been revealed (Viksne, Liston, Sapp, 1970[1]; Dellwig, Lewis and MacDonald, 1968[2]; MacDonald, 1969[3]), but also resulted in the construction of a topographic map at a scale of 1 to 250,000. With collection of such data the tactical military value of such a system was undeniable.

---

1 A. Viksne, T.C. Liston, and C. D. Sapp, "SLR Reconnaissance of Panama," Photogrammetric Engineering, v. 36, no. 3, pp. 253-259, March 1970.

2 L.F. Dellwig, A.J. Lewis and H.C. MacDonald, "Narrative Report for Geoscience Overlays, Darien Province, Panama," CRES Technical Report 152-1, University of Kansas Center for Research, Inc., Lawrence, Kansas, October 1968.

3 H.C. MacDonald, "Geological Evaluation of Radar Imagery for Darien Province," Modern Geology, v. 1, no. 1, pp. 1-62, November 1969.

RADAR WAVELENGTH VS RADAR FREQUENCY

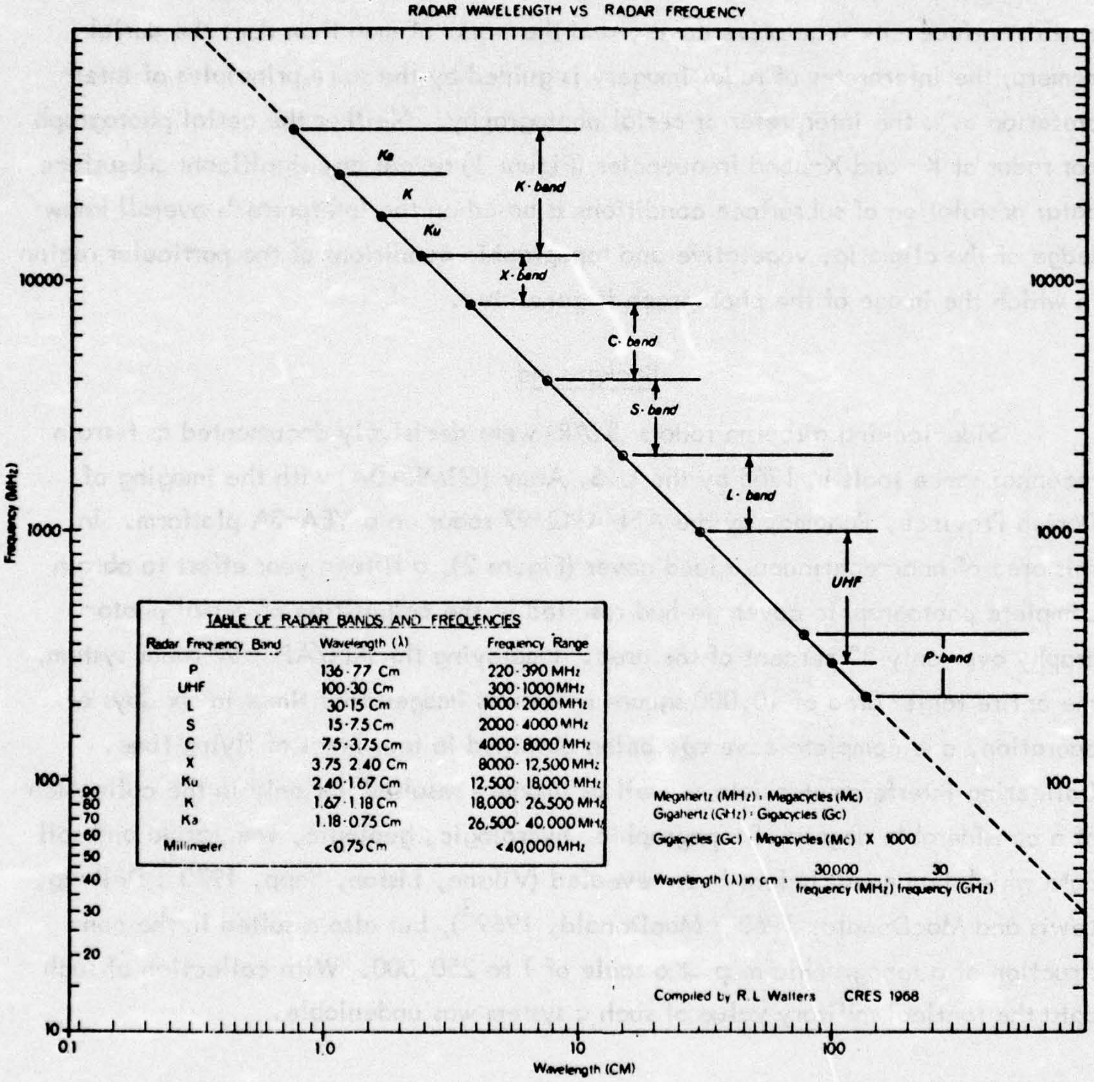

TABLE OF RADAR BANDS AND FREQUENCIES

Radar Frequency Band	Wavelength (λ)	Frequency Range
P	136-77 Cm	220-390 MHz
UHF	100-30 Cm	300-1000 MHz
L	30-15 Cm	1000-2000 MHz
S	15-7.5 Cm	2000-4000 MHz
C	7.5-3.75 Cm	4000-8000 MHz
X	3.75-2.40 Cm	8000-12,500 MHz
Ku	2.40-1.67 Cm	12,500-18,000 MHz
K	1.67-1.18 Cm	18,000-26,500 MHz
Ka	1.18-0.75 Cm	26,500-40,000 MHz
Millimeter	<0.75 Cm	<40,000 MHz

Figure 1

Radar wavelength vs radar frequency

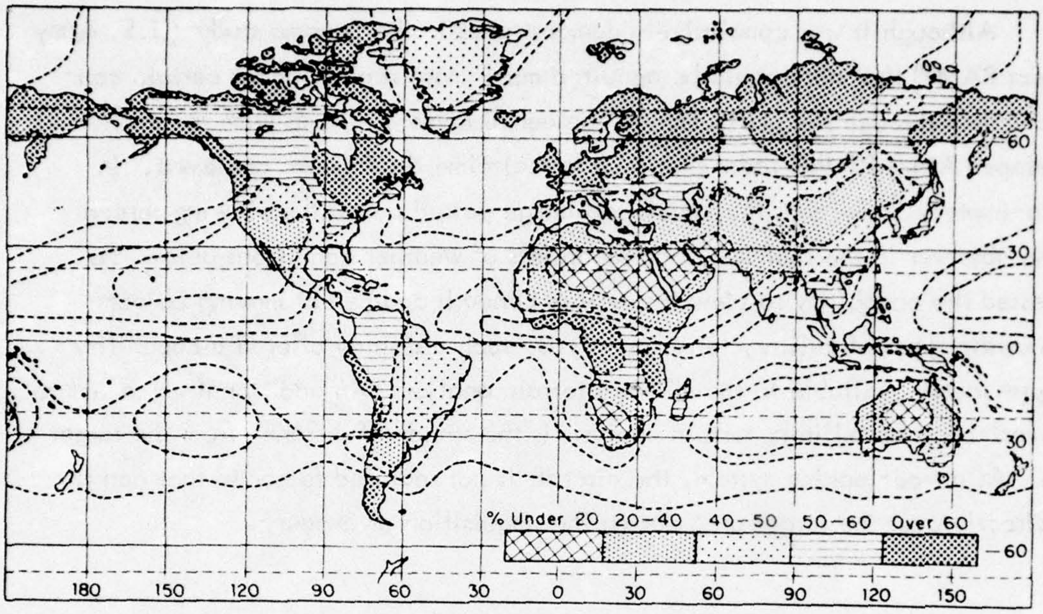

Figure 2 Mean Annual Cloud Cover for the World in Percent of Sky Covered (Rumney, 1968[4])

The Panama demonstration was particularly dramatic because of the capability of radar for gathering terrain data with almost complete disregard of climatic conditions. The demonstration of the capability subsequently led to the gathering of terrain data over large areas of Brazil, Peru, Colombia, Nicaragua, and Indonesia utilizing several military-developed radars, the use of which was sanctioned for commercial operation.

As important and undeniable as the cloud penetration capability of radar is, it also has been demonstrated that this capability is not the singular asset of such a system. Synoptic coverage permits the integration into patterns or trends of geologic or militarily significant terrain elements which might otherwise be identified as isolated features. The sensitivity of radar to micro-relief (surface roughness) and the dielectric properties of the target material give the image interpreter data which previously have not been available to him. These capabilities were well demonstrated but little publicized in Project Sand, Phase II, when radar imagery alone among all sensor presentations revealed the location of abandoned channels of the Mekong River.

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4 Rumney, G. R., Climatology and the World's Climates, MacMillan, New York, N. Y., 1968.

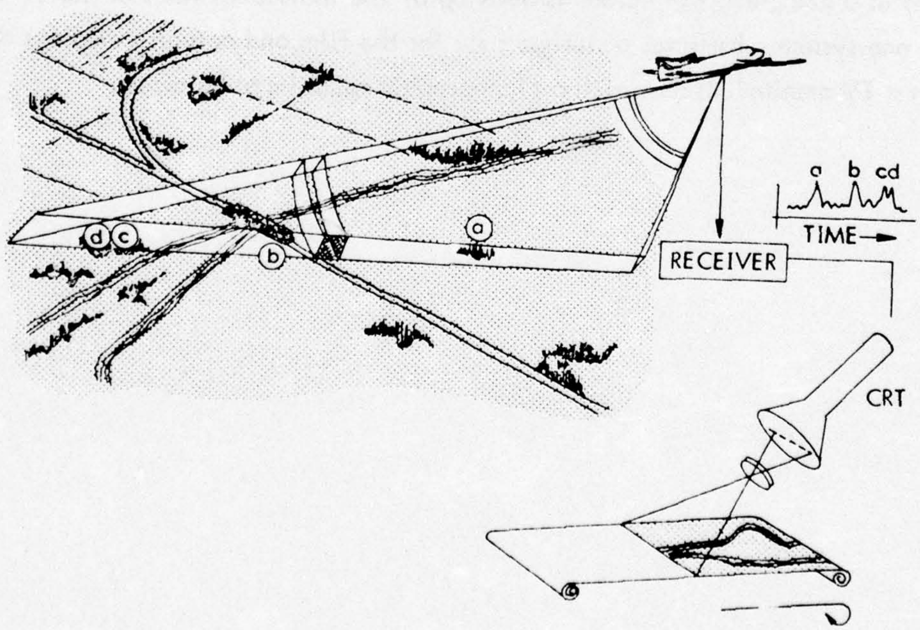
Although it was conclusively demonstrated in the Panama study (U.S. Army Project RAMP) that data could be acquired much more rapidly under certain conditions than through the utilization of the aerial camera, it was with the earlier developed AN/APS-94B radar that a near-real-time display was achieved. In approximately 90 seconds the developed image passed across the viewing screen of the observer in the Mohawk, and regardless of weather conditions below, he possessed the capability to view the terrain beneath and detect moving objects. For certain types of military terrain analysis, such a display offered a capability not previously available to the military terrain analyst. An additional value not to be overlooked for military terrain analysis is the stand-off distance from the target area. As a side-looking system, the aircraft is not required to nor in fact can it fly directly over the target area during the acquisition of imagery.

PRINCIPLES OF RADAR IMAGING*

Many variables in the design and operation of SLAR's influence the interaction between transmitted energy and terrain, and the resultant image. In any system resolution, dynamic range, incidence angle, scale factor, radar frequency (Appendix G) and polarization (Appendix H) may be subject to variation, and influence to a greater or lesser degree the return signal. The use of real aperture or synthetic aperture strongly influences the hardware complexity, but image variations often ascribed to difference in system type, are intrinsic to particular systems and processing schemes rather than to the use of real or synthetic aperture per se.

With the exception of the method for achieving along-track resolution, all SLAR systems operate in a similar manner. A transmitter generates repeated short bursts or pulses of radio frequency (RF) energy which are propagated into space by means of a directional antenna (Figure 3) which causes illumination of the surface

Figure 3. Diagrammatic Presentation of the Operation of a Real Aperture SLAR.



* For a more detailed explanation see Appendix F.

of the earth in a narrow path. At any one instant, the area of the earth's surface illuminated by the transmitted pulse is limited in the range direction by the physical length of the transmitted pulse in space and in the azimuth direction by the beam-width of the directional antenna. Objects which are reflective to the RF energy (a,b,c,d) will radiate back a fraction of the transmitted energy to the antenna from which it goes to the receiver for amplification and conversion to a video electrical signal. The amplitude of each return is a function of the reflectivity of the object to the RF energy and can be displayed similarly to one line of a television picture, by modulating the intensity of the beam of a cathode-ray tube (CRT) as the beam is swept across the face of the CRT.

As the antenna is repositioned during flight to "look" at a new strip of the earth's surface adjacent to the one previously imaged, another pulse of RF energy is transmitted and the return signal is displayed on the CRT. In operation, photographic film is moved past the CRT display line at a velocity proportional to the velocity of the aircraft. Thus, an image of the terrain illuminated by the transmitted RF pulses as the antenna beam is scanned along the earth's surface will be built up along the film, just as a complete TV picture is built up by the individual lines of the TV raster. At least one system substitutes a storage tube for the film and actually displays the result on a TV monitor, from which a photographic record can be made.

BASIC PRINCIPLE OF RADAR IMAGE INTERPRETATION AND PROCESSING*

Visual

Photo interpreters have tended to apply standard interpretation processes automatically to radar's pictorial formats primarily because of the pictorial format but partly due to recognition of the unique configuration of elements with characteristic shape. Unless the interpretation procedures and terminology are clearly understood in the context of the new sensor's output, the use of air photo terminology may lead to confusion. Unfortunately, the air photo terminology does not always transfer directly from photographs to SLAR images. The meanings of various standard photo interpretation terms for object recognition, such as slope, pattern, size (image geometry), tone and texture, and shadow, have to be modified for use in interpreting SLAR imagery.

Of the object recognition elements originally defined for photo interpretation, only shape, pattern and size have direct parallels in the interpretation of SLAR imagery. This must be qualified by the systems limitation (resolution) of the SLAR. Tone, shadow and texture, critical in any type of interpretation, are highly dependent upon the remote sensing system being employed, and no direct parallel exists for these terms between air photo and SLAR image analysis. In SLAR imagery, these terms are descriptive of backscatter (influenced by frequency, resolution and depression angle of the system) from the scene being sensed. Therefore, terminology originally developed for one system (aerial photography) should be employed with extreme caution to interpretation of imagery acquired by other systems, specifically SLAR, for although the format is visual, the data are not (Figures 4a,b). Several excellent manuals have been prepared to help train analysts in the transition from photography to radar imagery.

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* For a more detailed explanation see Appendix J.

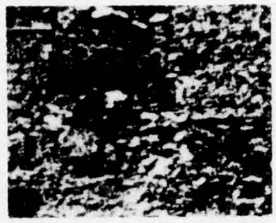
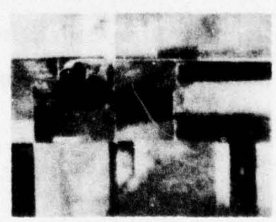
	SLAR IMAGE		PHOTOGRAPH
SHAPE-			
If objects are smaller than resolution cell size--	SHAPE	≠	SHAPE
The more the size of the object exceeds the size of the resolution cell, the more nearly--	SHAPE	=	SHAPE
PATTERN-			
Although Individual objects lose shape--	PATTERN	=	PATTERN
TONE-			
Sensing roughness and dielectric constant and influenced by wave-length, aspect angle, and resolution--	TONE	≠	TONE

Figure 4a
Interpretation Criteria

INTERPRETATION CRITERIA

TEXTURE-

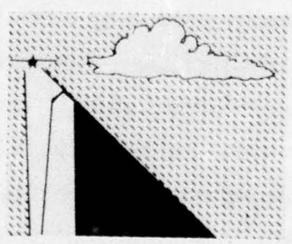
SLAR IMAGE

PHOTOGRAPH

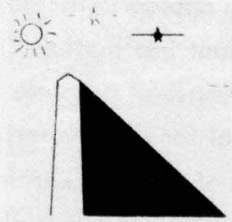
Also strongly influenced by system and target parameters--

TEXTURE = or ≠ TEXTURE

SHADOW and ILLUMINATION-



SYSTEM CONTROLLED



NATURE CONTROLLED

Figure 4b Interpretation Criteria

IMAGE PROCESSING TECHNIQUES*

The principal application of automated image processing for tactical terrain analysis is the optimization of the amount of information extracted by the analyst per unit time. This in turn implies that a highly interactive system with minimum hardware be provided to the analyst. Such a system (hardware and software) developed at the University of Kansas is characteristic of numerous systems being utilized throughout the scientific community. The rapid advances in solid state and computer technology make it increasingly likely that such a display device for utilization in tactical situations can now be developed.

A wide diversity of problems may be solved more effectively and rapidly utilizing automated image processing techniques. Particularly important in tactical terrain analysis is the generation of "factor maps". Using both analog and digital techniques, it is possible to produce a factor map directly from imagery. Subsequently, by digital processing, mathematical models are exercised to categorize such tactical activities or factors as air field construction, cross country troop or vehicle movement, and so forth.

Perhaps one of the single most important demonstrations for tactical terrain analysis, is the near instantaneous production of color coded maps, produced by the image analyst, utilizing conventional interpretation techniques. The interactive technique allows the interpreter to work with non-registered images, mentally correlating appropriate areas and rapidly producing a final category map. This has significant implications in tactical situations. Automated combination of registered radar images of the same scene but of different polarizations offer even greater potential for the revelation of tactical terrain data. The combination of the signatures of any element on two images may produce a unique signature in the combined presentation, which is almost instantaneously displayed for the interpreter.

Purely digital manipulation has proved to be of only limited value in tactical situations. In an interactive system, especially when utilized for terrain analysis, an automated system would make heavy use of the ability of digital processing equipment for bookkeeping and image manipulation. Enhancement, combination, level slicing, and other similar operations required by the image analyst to accomplish his mission, will be done by machine aids (optical, electronic, analog or digital)

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* For a more detailed explanation see Appendix K.

under the analyst's command, with the purpose of maximizing the information extractable from the imagery in the minimum possible time.

DEMONSTRATION OF APPLICATION OF PRINCIPLES OF INTERPRETATION IN TACTICAL MILITARY TERRAIN ANALYSIS

The recognition of objects or scenes on any pictorial presentation is based on the recognition of shape, pattern, size, tone, texture or shadow, or on the combination of two or more of these characteristics. In the analysis of radar, some of these characteristics are independent of such system parameters as frequency and polarization and, depending on the size of the object, resolution. Among these characteristics are shape, pattern, size and shadow. Other characteristics such as tone and, to a lesser degree texture, may be strongly dependent upon such system characteristics as frequency, polarization, resolution and depression angle at the radar or locally at the target.

In these analyses we have drawn upon scenes generated by a diversity of systems. Primary concern was utilization of examples of a wide variety of terrains rather than the utilization of imagery generated by a single system (Table 1). Although in some instances the results of these interpretations are not directly applicable to imagery of other systems because of differences in frequency, polarization or resolution, sufficient data are available from previous studies to postulate the data content of imagery of any particular scene generated by other radar systems. It is important that the reader be fully cognizant of the characteristics of the system which has generated the imagery being utilized, in-so-far as system parameters influence the return signal. For example, whereas the real-aperture AN/APQ-94 radar shows only major thoroughfares in the Phoenix area (Plate II), the AWTMS system not only reveals the total street pattern, but permits the detection of individual structures, this because of its better resolution. Knowing the parameters of each system permits the reader to better grasp the meaningfulness and value of the data extracted from a particular image, and to better visualize the extent of data content of imagery of a system or systems with optimum parameters for tactical military terrain studies. These data, in so far as available, are presented in Table 2 and Figure 5.

Table 1

Demonstration Areas

Area	Plate No.*	Primary Purpose of Evaluation
Freeport, Texas	I	Evaluate coastal terrain for amphibious operations and troop and vehicle movement on shore.
Phoenix, Arizona	II, III	Evaluate urban area and surrounding arid terrain for troop and vehicular movement and variation in data content with change in look direction and range.
Atrato Delta, Colombia	IV	Determine character of vegetation in tropical environment particularly as related to troop and vehicular movement and concealment.
Denver-Colorado Springs Corridor	V	Determine contrast in return from vegetation and man-made objects in winter and spring seasons.
Connecticut River Valley New Hampshire and Vermont	VI	Evaluate an area of rolling hills and woodlands analogous to North-central European rural countryside.

* Plates are in the form of transparencies and may be found in packet.

TABLE II

RADAR SYSTEMS SPECIFICATIONS

RADAR SYSTEM	MANUF.	WAVELENGTH OR BAND	TYPE	RESOLUTION ALONG TRACK	RESOLUTION ACROSS TRACK	SWATH WIDTH	POLARIZATION
		mm.		Meters	Meters	km	
AN/APD-7	W	8.6	Real				
AN/APD-8	W	8.6	Real				
AN/APD-10	GY	31	Syn.	10	10		HH
AN/APQ-55	TI	8.4	Real				
AN/APQ-56	W	8.6	Real	2.27xR	15	27*	HH
AN/APQ-69	GY	31	Real	$25 \times R_{km}$	15	25	
AN/APQ-97	W	8.6	Real	$1.7 \times R_{km}$	9	10 - 20*	HH and HV
AN/APQ-86	TI	8.6	Real	$3.1 \times R_{km}$	15	16	
AN/APQ-102	GY	31	Syn.	15	15	35 to 90	HH
AN/APS-73 XH-1 XH-2 XH-3 XH-4	GY	31	Syn.	15	15	92	HH
AN/APS-85	M	25	Real	$7.7 \times R_{km}$	75	100	HH
AN/APS-94 A B C	M	25	Real	$7.7 \times R_{km}$	75	100	HH
AN/APS-94 D	M	32	Real	$7.7 \times R_{km}$	30	100	HH
AN/DPD-2	P	18	Real/ Syn.	30-60	12 to 25	18	Transmits & Receives in Both
AN/UPD-4	GY						
GEMS	GY	31	Syn.	15	15	37.0	HH
MMR (FARMAR) FLAMR	H		Syn.				
MICHIGAN	UM	30	Syn.	15	15	18.5	Transmits & Receives in Both
		200	Syn.	10	10	18.5	Transmits & Receives in Both
AWTMS (APQ-152)	GY	X	Syn.	3	3		
Polyfrequency Radar device	GY						Multiple Polarization
NASA Scatter-ometers	Ryan Model 707	22.5		25 at 1000 m	25	NA	VV
		750		35 at 3000 m	55	NA	Transmits Both Receives Both
NRL 4FR	RN	34 67 245 700	Real/ Syn.				HH, HV, VV, VH
Blue Shadow	K	30	Real				
P391	E	8.6	Real	$3.5 \times R_{km}$	15	28	HH
RAFALE	TC	33	Syn.				
TOROS		20	Real				
VENUS FLY BY	H	250	Syn.				
14/9R2							
440 MHz Radio Echo Sounder		680					

Key to Manufactures

E = EMI
GY=Goodyear
H = Hughes Aircraft Co.
K = Kelvin Hughes
M = Motorola
P = Philco-Ford

RN = RCA and NRL
TC = T-CSF
TI = Texas Instruments
UM = University of Michigan
W = Westinghouse

*Both Sides

AN/APQ - 97 (A) ——— modification letter

type of installation

equipment number

purpose

type of equipment

Relevant examples of indicator letters:

Type of installation:	A - Airborne D - Pilotless Carrier U - General purpose, includes two or more classes
Type of equipment:	P - Radar
Purpose:	D - Direction finder and/or reconnaissance Q - Special or combination of purposes S - Detecting range and/or bearing

Figure 5

U. S. Military Nomenclature System

Freeport, Texas*

(Plate I)

Radar System	Manuf.	Wavelength(mm) or band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath (km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7xR_{km}$	9	10-20	HH and HV

Purpose

This evaluation of imagery was designed to demonstrate the degree to which data could be extracted from relatively coarse resolution imagery pertinent to amphibious operations and inland troop movement in a gulf coastal environment.

The topography of the area is typical of the Gulf Coastal Plain, virtually with no extensive stands of trees. Swamps or marshes are limited to the area near the mouth of the Brazos River.

Results

Relative relief in this low flat terrain was easily defined, natural (swamps, rivers, etc.) and man-made (urban complex features, canals) obstacles to troop and vehicular movement were identified, and these data, along with the knowledge of density, relative height and type of vegetation, and soil character, facilitated the planning of movement of both foot and vehicular elements inland from the shore. Water-land interfaces were well defined and with improvement in resolution, relatively accurate measurements of width of water courses could be made. Identification of unobstructed beach zones defined optimum locations for landing. Urban residential and industrial complexes were easily separated.

Conclusions

A combination of low relief, pronounced offshore features, sharply defined water bodies, meandering streams and uniformly low vegetation permit the interpreter to derive a great amount of pertinent military terrain data from this image, in spite of its coarse resolution. With improvement of resolution, additional data in urban areas would become available. In the Dow Chemical complex, tanks are identifiable as such because of their size relative to resolution, but with resolution improvement, other elements of the complex would become

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* For details of analysis see Appendix A.

identifiable also. The combination of like and cross polarizations further enhances the value of the imagery in revealing contrasts in relative soil moisture, a factor particularly critical in low relief coastal areas. Most, if not all information needs for an over-the-shore operation toward a limited objective, such as the Dow plant, would be provided through an analysis of this image.

Phoenix, Arizona*

(Plates II, III)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Across track	Swath(km) Width	Polarization
AN/APS-94D	M	25	Real	$7.7xR_{km}$	30	100	HH

Purpose

The Phoenix, Arizona area offers an excellent opportunity to utilize imagery produced by an operational Army radar for evaluation of an urban region of more than one million residents and the surrounding arid terrain. Laid out in a north-south east-west grid typical of the flat, arid regions of the western United States, multiple looks offer the opportunity of demonstrating the relationship between cultural feature orientation and look direction. In addition, in the adjacent areas characterized by isolated mountains bordered by gently sloping alluvial fans, the relationship between look direction, depression angle and apparent relief can be considered. Vegetation is restricted to a variety of shrubs, small trees and cacti.

Results

Due to the coarse resolution of the imagery, only highways and major streets can be identified. A rural road network is well developed and easily detected. Particularly in rural areas where the contrast with adjacent terrain is strong, railroads are easily detectable, especially when oriented parallel to the flight direction. Power lines are characterized by the strong return from the large, metal, supporting towers, regardless of the orientation of the transmission line relative to the look direction.

Water bodies and water courses, natural or man-made, are easily detected because of the strong contrast with the adjacent terrain. Water filled ditches may be easily separated from dry ditches because of the contrast in specular return from the surface of the water body and diffuse return from the bottom of the dry ditch. Bridges across water bodies are easily detected in spite of small size and coarse resolution because of a line of high return which traverses the water course.

Variations in elevation, the degree of dissection, and the overall slope of the surface enable the interpreter to map mountains, old alluvial fans, young alluvial fans, and alluvial plains. With the knowledge of the climatic conditions

* For details of analysis see Appendix B.

and the erosional processes characteristics of the Sonoran Desert region and from the data at hand, the interpreter can easily extract from the imagery data concerning character of the soils, depth of the soils, depth to water, and the ease with which troops and vehicles might expect to traverse the various terrain types.

Conclusions

In the urban area, commercial and residential areas can be easily delineated and the main arteries defined using this imagery. Highways, secondary road networks, and railroads can be traced into and through the rural areas, although to some degree their identification is look direction dependent. Water bodies, because of the strong contrast between the surface of specular return and the adjacent areas of diffuse return, are easily identified and routes for potential crossings are apparent. The degree of filling of water courses can easily be determined. Then these data, which are critical from the military point of view, can easily be updated because of the near real time capability of radar systems.

In the area surrounding Phoenix, the degree of dissection of alluvial fans is indicative of the ease with which men and vehicles can maneuver. Relief is accentuated when arroyos are parallel to flight direction. Multiple looks not only assure a more accurate determination of the degree of dissection of the surface, but also provide the interpreter with data which will permit reasonably accurate slope determinations.

The moderate resolution will not fully support urban area operations information needs. Despite this, the Army operational radar does provide a wealth of regional terrain data, some of which is more efficiently generated and extracted from this imagery than from the imagery of fine resolution narrow swath system.

Atrato Delta, Gulf of Uraba, Northwestern Colombia*

(Plate IV)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath(km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7xR_{km}$	9	10-20	HH and HV

Purpose

An often demonstrated value of radar imaging is the utilization of high frequency systems in the mapping of plant communities. In the Atrato Delta region of northwestern Colombia one finds an excellent opportunity for the demonstration of this capability. Utilizing the radar image and with a knowledge of delta development and tropical vegetation types, the interpreter can easily generate factor maps presenting all tactical terrain data necessary for an amphibious operation and the subsequent movement of troops and materials inland.

Results

The key to the derivation of data in this environment is identification of vegetation types. Vegetation communities in this tropical deltaic area are intimately associated with terrain elements, and the identification of the communities enables the classification of terrain types, even in this region of low relief, where accentuation through shadowing is restricted to the adjacent mountainous areas. Thus, positive identification of mangroves along the coast defines such areas as areas extremely difficult for movement although offering excellent concealment of troops. In a similar manner, the identification of lines of vegetation immediately adjacent to the distributary channels defines the position of natural levees on which the land surface stands higher than the back swamp regions.

Conclusions

Although hampered by coarseness of resolution which does not permit accurate determination of the percentage of terrain covered by canopy, this relatively coarse resolution radar more than suffices in the providing of adequate data for the isolation and (with corroborative data) identification of plant communities. From such data, along with a knowledge of regional characteristics and deltaic growth processes,

* For details of analysis see Appendix C.

most of the significant data necessary for a military operation in this environment is provided. The military value of radar in a "worst-case" environment is shown. Photography has frequently been ineffective in such areas.

Seasonal Dependence of Radar Return Signals in the Denver - Colorado Springs, Colorado Corridor*

(Plate V)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath(km) Width	Polarization
AN/APQ-102	GY	31	Syn.	15	15	35 to 90	HH

Purpose

This analysis was designed to demonstrate the influence of seasonal terrain variations on radar return signals. A winter image generated on February 23, 1972, was compared with a spring image generated on May 25, 1972. Signatures from natural terrain and from man-made objects show sufficient variation in the two images to emphasize the importance of seasonal updating of data bases.

Results

The near uniform dark tones of dormant and dead vegetation as seen on winter imagery provide a background against which high relief features such as buildings, fences, power lines and tall trees and shrubs are enhanced. However, during growth seasons, imagery (spring) provides the data necessary for the identification of low natural vegetation, crop types, field conditions and soil textures. Such data are revealed because of the sensitivity of radar to the geometry of the individual crop or natural vegetation element. The importance of contrasts in surface roughness is further illustrated by the strong contrast between the no-return of an airport runway and the surrounding vegetated areas on spring imagery, and the weak contrast between the airport runway and dormant grasses on winter imagery.

Particularly in the mountainous areas to the west of the Denver - Colorado Springs corridor, and to a lesser extent in the rolling hills and plains to the east, enhancement of the terrain through shadowing has enabled the separation of the area into six regions, each of which has a characteristic surface configuration.

Conclusions

Well demonstrated in this area is the extreme sensitivity of high frequency radar systems to the surface geometry or micro-relief of the imaged area. For obtaining optimum terrain and target data, multiple seasonal coverage is desirable.

* For details of analysis see Appendix D.

As important as it might be to know the location and nature of works of man which might impede the movement of troops or vehicles, it is equally important to have knowledge of the crop type, its growth stage and its resulting value at any moment in time for the concealment of troops or vehicles.

Connecticut River Valley-

Vermont and New Hampshire*

(Plate VI)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath(km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7 \times R_{km}$	9	10-20	HH

Purpose

A 30 mile long section of the Connecticut River Valley in Vermont and New Hampshire was selected for evaluation as an analog of a mid to Northern European environment. The imagery covers the river valley surrounded by woodlands of intermediate relief and interlaced with highways and rural roads. Windsor and Bellows Falls, Vermont and Charlestown and Clairmont, New Hampshire are included.

Results

In close proximity to the river itself were easily defined a major divided highway along with some additional secondary roads, a power line and a railroad. Outside of the river valley the proximity of the secondary roads to the three-lined stream valleys impeded identification of the roads. In a similar manner, in the agricultural areas secondary roads appear to be shielded in many instances by woodlots and hedge rows. In urban areas, business districts can be isolated from residential areas on the basis of increased intensity of the return signal. Power lines leading away from the dam at Bellows Falls, Vermont suggest the presence of a hydro-electric facility as does the industrial development along the river downstream from the dam. Lines of high return which cross the river and from which lead roadways are indicative of bridges. Vegetation can only be divided into two major categories, forest and non-forest, the forest area, because of closed canopies, being identified as areas of excellent concealment.

Conclusions

Although major lines of communication can be mapped without difficulty, in areas such as these, where secondary road systems follow stream valleys, carved through heavily wooded areas, or are paralleled by hedge rows or trees,

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* For details of analysis see Appendix E.

identification is difficult. With the knowledge of depression angles, using the shadow technique, it is possible to make estimates of terrain slopes. Overall vegetation patterns can be mapped and areas of concealment can be easily identified.

CONCLUSIONS

The potential role of SLAR in tactical military terrain analysis was first dramatically demonstrated in Panama in 1965 when terrain data were revealed in many regions of Darien Province for the first time. In such an area of cloud cover, only radar could provide data; the need for its utilization under such conditions being further demonstrated through its use in data collection in Brazil, Venezuela, Colombia, Peru and Indonesia where aerial photography is hampered by climatic conditions. However, one need not look to high percentage cloud covered regions for a demonstration of the use of SLAR as a prime sensor in the collection of tactical military terrain data. In July, 1965, the photographic portion of a commercial mission scheduled over central Arizona for the SLAR imaging and aerial photography was delayed because of cloud cover. After two weeks, the photographic portion of the mission was canceled. In terms of need for data on a rapid turn around basis, the 24 hour imaging capability of SLAR is unique. Furthermore, with cover of darkness preferred for covert movement and safer for reconnaissance as well, for military target and terrain reconnaissance, radar is essential.

In aerial photography, regardless of film-filter combinations and flight parameters, sensing is in the very narrow visible and near infrared portions of the electromagnetic spectrum. A certain minimal degree of resolution is expected and even small-object recognition is generally based on shape, relative size or color or a combination of these elements.

Such is not the case for SLAR. Sensing is in a much broader region of the electromagnetic spectrum. System parameters play an important role in the generation of the image, and the requirements of a mission dictate the parameters of the system to be utilized. More options are available for an optimized military radar system.

In all areas analyzed, it has been pointed out that improvement in resolution would undoubtedly provide more data, this being best demonstrated in the urban Phoenix, Arizona area. Finest resolution being achieved in synthetic aperture systems, one might logically conclude that this would preclude the utilization of real aperture systems. In exclusive utilization of synthetic aperture systems, one may eliminate one of the major capabilities of radar, that is near real time

display, which is at this time restricted to the real aperture system. Thus for non-time dependent data collection, particularly in urban areas, synthetic aperture systems seem best fitted for the role, whereas for updating of data on a more timely (field) basis, particularly if detection is sufficient and recognition might be realized through correlation with other data or through position or relationship in the scene, the need for real aperture system is demonstrated. The two systems could supplement and complement each other.

In the event that near real time display might be achieved with synthetic aperture systems and that system cost becomes comparable, it cannot be assumed that the sole aim in radar development is the improvement of resolution. Although Rydstrom (1970)[5] concluded that fine resolution imagery contained, in addition to new data, all of the data contained in coarse resolution imagery, insufficient documentation as well as the removal of his investigation from a limiting time frame suggest the contrary. An early study (Dellwig, et. al., 1966)[6] pointed to instantaneous recognition of linear terrain elements in the Boston Mountains of Arkansas, elements which had not been previously detected. In Viet Nam (Project SAND, Phase II)* abandoned channels of the Mekong River in the delta area were first recognized on coarse resolution radar imagery, and after identification and with knowledge of their location, identified on aerial photographs. In the first instance coarseness of resolution and suppression of otherwise distracting detail were considered responsible for the display of the linear elements. In the Mekong Delta, suppression of detail combined with a difference in dielectric properties, due to differences in moisture content in the channel and adjacent floodplain, were responsible for the identification of the channels.

Effectively demonstrated in the Atrato Delta and the Freeport, Texas area was SLARs' capability for providing information needed for an amphibious landing and inland movement through the entire spectrum of terrain surfaces of troops and

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5 Rydstrom, Hubert O., Capabilities of Advanced Radar Systems for Monitoring Land Resources, Goodyear Aerospace Corporation, GERA-1604, 26 May 1970.

6 Dellwig, L.F., J.N. Kirk and R.L. Walters, "The Potential of Low Resolution Radar Imagery in Regional Geologic Studies," Journal of Geophysical Research, vol. 71, pp. 4995-4998, 1966.

* ETL Study-Limited Distribution.

vehicles. The location of offshore features and the definition of vegetation types and densities and onshore water bodies which might act as barriers for troop or vehicular movement was achieved to such a degree that, if necessary, a military operation could be conducted without supplemental information. In the arid Phoenix, Arizona area similar data critical for troop and vehicle movement were also revealed but in that more rugged terrain it was dependent to some degree on look direction and depression angles, both parameters being controllable.

Critical in tactical military intelligence and terrain analysis is the recognition and identification of man-made elements, both fixed (fences, power-lines, structures, etc.) and mobile (automobiles, trucks, tanks, etc.). Although fine resolution radars are necessary for identification of some of these elements, even coarse resolution systems sometimes prove to be almost as effective as the aerial photograph for detection. For many such elements detection and relationship to other elements in a scene suffice for identification. It should be remembered that radar detection capability may be several factors finer than the system's resolution capability.

When efficiently utilized, the advantages of the side looking configuration outweigh the disadvantages, not the least of which is the stand-off distance of the aircraft from the target. System generated shadows present the image interpreter with a scene as is observed obliquely with the human eye and rapid interpretation is facilitated. In addition, shadows enable at least semi-quantitative determinations of elevation. Dual looks from orthogonal directions not only eliminate most data loss through shadowing but provide data for slope estimate. Dual looks from opposite directions eliminate all shadow loss, although this may not be necessary with proper selection of depression angles relative to local relief. Ground measurements pose no serious problems to a trained interpreter who has a knowledge of system parameters. With the aid of a map, ground measurements can be useful for a variety of technical uses.

Diversity in system parameters, versatility in utilization, uniqueness of data revelation, and operation independent of climatic conditions should assure SLAR a continuing role in the acquisition of tactical military terrain data. That the full capability does not yet exist for field use leads to the inevitable conclusions that:

a. Present knowledge must be consolidated and placed in the doctrine and training literature

b. Advanced technology, doctrine and training materials should be developed based on analysis of the full range of tactical requirements and the shortfall remaining after step "a" above.

It is not unreasonable to believe that step "a" could be completed by the end of 1977 and step "b" by the end of 1980 if appropriate resources are allocated.

APPENDIX A

FREEPORT, TEXAS

(Plate I)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath(km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7xR_{km}$	9	10-20	HH and HV

Terrain and Cover Characteristics

Freeport, Texas with a metropolitan area population of approximately 52,000 straddles an abandoned channel of the Brazos River within several miles of its entrance to the Gulf of Mexico. The river channel was artificially diverted to the southwest, the former channel now serving primarily as a barge route to the Dow Chemical plant situated in a major meander loop of the river downstream (southeast) from Freeport and easily identifiable by the prominent tank farms (TF, plate I). Seaward from Freeport, the intracoastal waterway appears as a prominent linear channel parallel to the coast.

The topography of the area is typical of the Gulf Coastal Plain, virtually flat, the result of seaward building of the land brought about by the deposition of deltaic sediments. Relief averages less than 10 feet.

The vegetation is dominated by grasslands and there are no extensive stands of trees. Swamps or marshes are limited to the area near the mouth of the Brazos. Grasses are medium tall to tall, often very dense. The dominant grass is smooth cordgrass.

Results of Analyses (Plate 1, Overlay)

The deltaic area of the Brazos and vicinity has a singular plant community cover. In spite of the coarseness of resolution, varying degrees of vegetation density and the associated capability of concealment can be identified.

Communication Networks

Water bodies are easily defined because of their high contrast with the adjacent land surfaces and showing dependence on look direction or depression angle. This is especially true if they are elongate bodies not covered by overhanging trees or shadowed by high adjacent shoreline growth. Man-made objects are to some degree look direction dependent and for maximum revelation and area

they should be imaged from two directions normal to each other (Lewis, MacDonald, Simonett, 1969)[7].

R	Roads and highways
U	Built-up areas with regular road networks
RR	Railroads
C	Canals
S	Streams
P	Protected offshore channel to the sea

Near Shore Conditions and Amphibious Landing Sites

Area 5	Offshore mainly submerged alluvial bars, area behind the bar consists of irregular small bodies of standing water. Poor offshore landing capability.
Area 6	Long shore partially submerged alluvial bar, capable of supporting offshore troop landing.
Area 7	Unobstructed beach zone, capable of supporting landing of troops and equipment.

Surface Configuration

Relief in this region is essentially negligible and estimates of relative relief are difficult. A simple technique of developing a pseudo-stereo presentation with monoscopic imagery is the overlaying of a negative transparency on a positive with slight offset (Dellwig et. al., 1970)[8] (Figures A-1a,b). Interpretation is not only improved, but interpretation time is reduced. (Such photo processing should be at the disposal of military intelligence interpreters working in a tactical interpretation facility.)

Area 1	Gently sloping unobstructed beach.
Area 2	Gently rolling coastal topography covered by herbaceous vegetation of varying height and density. Water courses and water bodies provide the only obstruction.
TF	Tank farm

7 Lewis, A.J., H.C. MacDonald and D.S. Simonett, "Detection of High Return Linear Cultural Features on Multiple Polarized Radar Imagery," Proc. 6th Symp. on Remote Sensing of Environment, University of Michigan, Ann Arbor, pp. 879-894, October 1969.

8 Dellwig, L.F., H.C. MacDonald and J.N. Kirk, "Technique for Producing a Pseudo-Three-Dimensional Effect with Monoscopic Radar Imagery," Photogrammetric Engineering, pp. 987-988, September 1970.

W	Standing water
S	Natural streams
O	Oxbow lakes
M	Marsh or swamp with some standing water
C	Canals
U	Built-up area, residential and industrial
B	Bridges
T	Terrace

Vegetation and Concealment

Area 1	Dense, herbaceous vegetation found in topographically low areas; maximum height 5 feet. Capable of concealing scattered individuals.
Area 2	Medium dense herbaceous vegetation found on relatively high areas; maximum height 3 1/2 ft. Very limited concealment capabilities.
Area 3	Short to medium tall herbaceous vegetation of medium density; maximum height 2 1/2 ft. Poor concealment capability for more than one man.
Area 4	Beach vegetation consisting primarily of relatively small patches of medium tall grass, between 1 1/2 and 2 1/2 feet in height. Essentially no concealment value.
U	Built-up area, unvegetated.
S	Natural streams
C	Canals
W	Standing water

Soil and Soil Depth

Data are estimated with knowledge of sedimentary processes in a deltaic area in the Gulf Coast.

Area 1	Beach sands, unconsolidated, depth greater than 15 feet (estimated).
Area 2	Alluvial soils of fine sediment, depth greater than 15 feet (estimated).

Figure A-1a. Print of positive radar imagery, vicinity of White Lake, Louisiana

Figure A-1b. Pseudo-three-dimensional effect produced by superposition (with slight offset) of positive and negative transparencies.

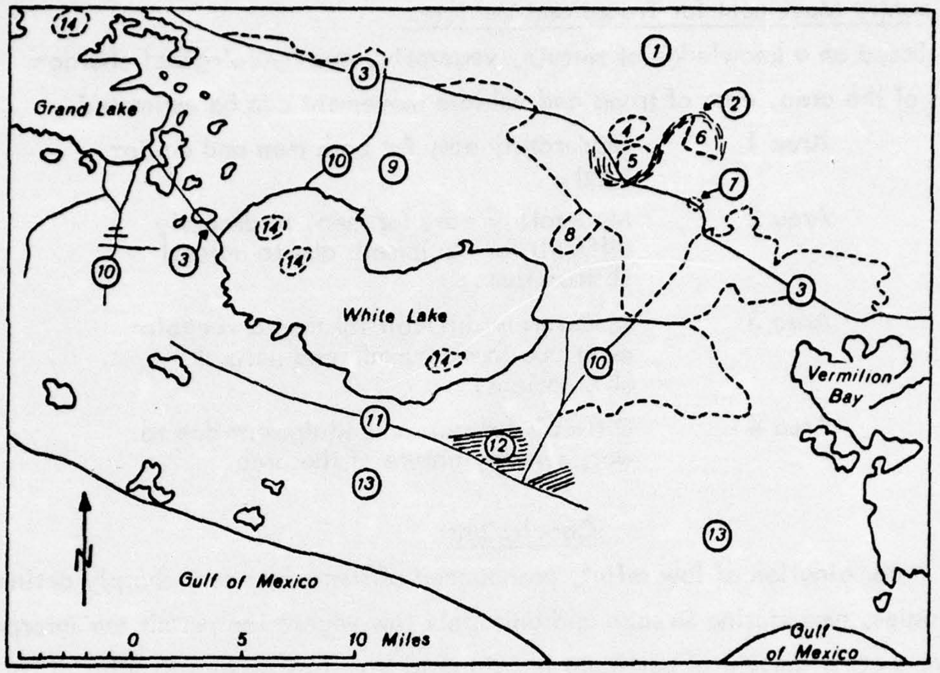

Figure A-2. Land-Use Map

1. Cultivated land
2. Meander scars
3. Intracoastal waterway
4. Dog Island
5. Green Pine Island
6. Third Island
7. Town of Forked Island, Louisiana
8. Gravel pits
9. Non-cultivated (grassland-Southern Cordgrass Prairie)
10. Canals
11. Abandoned beach
12. Beach ridges
13. Coastal marshland
14. Oil well platforms

Cross Country Movement for Troops and Vehicles

Based on a knowledge of terrain, vegetative and hydrological characteristics of the area, ease of troop and vehicle movement can be estimated.

Area 1	Moderately easy for both men and equipment.
Area 2	Moderately easy for men, moderately difficult for equipment due to natural obstructions.
Area 3	Moderately difficult for men and equipment due to man-made and natural obstructions.
Area 4	Difficult for men and equipment due to wet, swampy nature of the area.

Conclusions

A combination of low relief, pronounced offshore features, sharply defined water bodies, meandering streams and uniformly low vegetation permit the interpreter to derive a great amount of pertinent terrain data from this image, in spite of its coarse resolution. With improvement of resolution additional data in urban areas would become available. In the Dow Chemical complex, tanks are identifiable as such because of their size relative to resolution, but with resolution improvement, other elements of the complex would become identifiable also. This area has permitted an unusually complete analysis representative of tactical information required for an over-the-shore action. All the information required to move men and equipment from offshore to an objective, e.g., the Dow Chemical complex, is revealed.

APPENDIX B
PHOENIX, ARIZONA
(Plates II, III)

Radar System	Manuf.	Wavelength(mm) or band	Type	Resolution (m) Along track	Across track	Swath(km) Width	Polarization
AN/APS-94D	M	32	Real	$7.7xR_{km}$	30	50	HH

Terrain and Vegetative Cover Characteristics

Phoenix, Arizona and its satellite cities rise as an oasis along the Salt River Valley in Central Arizona and are located in the Sonoran Desert segment of the great arid Basin and Range country of the southwestern United States. It is an area of sparse vegetation except where irrigated.

The population of Phoenix and its satellite cities exceeds 1,211,000, more than half of the population of the entire state. In an area of low-land value, except where irrigated, one finds a city dominated by low rise structures, except in the central business district where high-rise modern structures have been developing since the revitalization of the city in 1971. Street patterns are typical of the flat arid western regions of the United States, being laid out in a north-south east-west grid.

The vegetation of the Phoenix area is primarily that of the Sonoran Desert although one finds small areas of deciduous riparian forest, grassland, and chaparral (Turner, 1974)[9]. Three plant communities, which extend from the river bottom to a maximum elevation of 4,500 feet on steep southerly slopes, are recognized. The valleys are dominated by the desert saltbush community, the principal shrub of which is the saltbush, a gray two to five foot tall shrub, which grows in the fine-grained alluvium that fills the valleys. The lower and more arid slopes which rise from the valley floor are of loamy, sandy soil and are dominated by the creosotebush, for which the community is named. The plants of this community occupy the flat terrain or slightly tilted plains surrounding the mountains. The height and spacing of the creosotebush attest to the aridity of the area. Occupying the bajadas and mountain slopes above the creosotebush community is the paloverde-saguaro community, a

[9] Turner, R.M., Map Showing Vegetation in the Phoenix Area, Arizona, U.S. Geological Survey, MAPI-843-I, Reston, Virginia, 1974.

complex assemblage of small trees, shrubs, and cacti. In these areas of coarse soil, the plant life shows a diversity and density which exceeds that in the lower slope creosotebush community region.

Results of Analysis (Plate II, Overlay)

Lines of communication

Only highways and major streets are shown. In urban areas, the street network is very dense and streets are difficult to separate at this resolution. However, major streets do stand out especially with oblique look directions. In the intensive agricultural areas surrounding Phoenix, the rural road network is well developed on a township and range grid, with roads a half mile or one mile apart in most areas.

Railroads appear to be closely aligned with highways and are difficult to detect except when they are parallel to the flight direction; with this orientation they have a characteristic high return. The long straightaways and curves with large radii of curvatures are also characteristic of railroads. Railroads and highways are both difficult to trace through urban areas.

Several power lines have been mapped in the Phoenix area based on the return from large metal support towers. These towers have different appearances on real aperture radar imagery depending on look direction and range. In the near range the towers appear as small bright dots. However farther out in range, the dots become elongated in the direction of flight, due to the degrading of the azimuthal resolution as a function of range, while the range resolution remains constant. When power lines trend oblique to look direction, the elongated blips are arranged in echelon. Power lines trending parallel to flight direction in the far range may appear as bright lines similar to railroads, since the elongated returns from the towers coalesce into a solid line. Towers in the near range may be difficult to detect because of their size, although normally they act as excellent corner reflectors. Power lines are most easily detected in the mid to far range as long as they are not aligned parallel to flight direction in the extreme far range.

Visible in the Phoenix area are several canals which most likely bear water for irrigation. Canals are characterized by dark returns and trace out broad sweeping curves which are subparallel to contour lines. Canals or irrigation ditches which are water-filled would appear as lines of no return, because of specular reflection from the smooth surface, which would merge with the shadow

zone on the near side of the ditch. Dry canals or ditches would be marked by a relatively narrow shadow zone (the width being determined by depth of ditch and depression angle), a zone of moderate return from the bottom area, and high return from the far side due to the corner reflector effect caused by the ditch configuration (Figure B-1). Canals also disrupt field patterns.

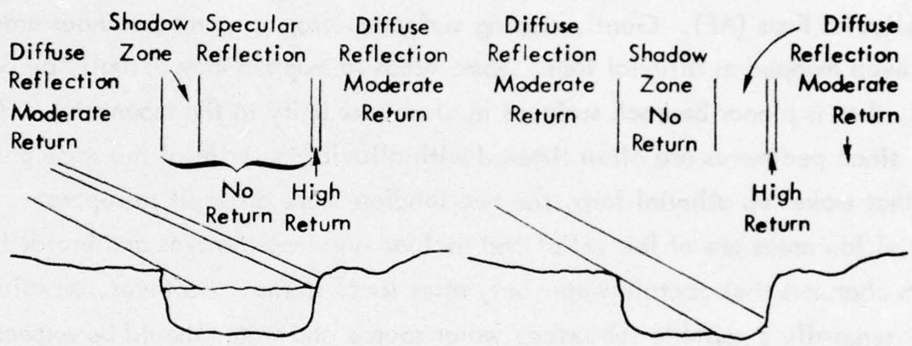

Figure B-1. Contrast in return from water-filled and dry ditch.

Several bridges have been mapped in the Phoenix area which cross the dry Salt River just south of town. Since this river is a braided stream and unnavigable, these bridges are most likely not very high.

Four major airfields are identifiable in the Phoenix area. One is situated in the urban area and is most likely the municipal airport (Sky Harbor). The other three are situated outside Phoenix proper with small built-up areas around them, suggestive of military airfields. What may be a small municipal airfield is located on the southeast outskirts of Phoenix (Scottsdale).

<u>Surface Configuration</u>

Four general classes of surface configuration can be identified in the Phoenix area:

(1) Mountains (M). Large mountain masses exist to the east of Phoenix and smaller ranges can be identified in other areas. Small outliers and inselbergs are also mapped as mountains, some of these existing within the city limits of Phoenix itself. Mountains in this area are rugged and show active dissection; as a result, they possess medium to high relief, steep slopes and sharp, well-defined divides.
(2) Old Alluvial Fans (OF). Areas of old alluvial fans are mapped to the northeast of Phoenix. These areas stand higher than younger alluvial fans and show a higher degree of dissection, low to moderate relief and flat divides.
(3) Alluvial Fans (AF). Gently sloping surfaces surrounding mountainous areas have been mapped as alluvial fans. Some areas so mapped may actually be pediments, that is planar bedrock surfaces in close proximity to the mountains. However, since pediments are often littered with alluvial material of the same general type that makes up alluvial fans, the two landforms are difficult to separate. Alluvial fan areas are of low relief and include numerous arroyos and braided stream channels that contain water only after local storms. However, an alluvial fan is generally a reliable subsurface water source and water should be expected to be found at shallowest depth near the base. Relief is best displayed when the prevailing drainage direction is orthogonal to look direction.
(4) Alluvial Plains (AP). The nearly level areas beyond the alluvial fans have been mapped as alluvial plains. These areas are composed of finer-grained material winnowed out of the surrounding alluvial fans. Relief is minimial in most areas; however, relief is more pronounced close to water courses, especially the Salt River which flows east to west just south of Phoenix proper. This river appears dry at the time of imaging and may be dry for a large part of the year. The alluvial plains contain virtually all of the urban areas and agricultural land.

<u>Soils and Bedrock</u>

Soils are generally poorly developed throughout the area; being absent to very thin and rocky in the mountains and on exposed pediment surfaces. Soils may be better developed on alluvial fans but would still contain much coarse material. The alluvial plains would possess the deepest and best developed soils because of the higher content of fine material, the latter in part indicated by the agricultural practices of the area.

Bedrock dominates the mountainous areas and also protrudes as small isolated blocks within the vast area of sediment cover. Depth to bedrock in the alluvial fans and plains increases away from the mountainous areas, probably measuring in 100's or even 1000's of feet.

Vegetation

Natural vegetation is very sparse in the Phoenix area, apparently restricted to low shrubs with considerable open space between, inasmuch as surface materials appear to dominate the return from natural terrain surfaces. The only possible vegetation patterns detected are in the area northwest of the White Tank Mountains and in an area south-southeast of Phoenix (Plate III, Veg.). These patterns appear to be caused by phreatophytic vegetation, probably trees, along some of the arroyos in the alluvial fan areas. The patterns are seen best in the far range and are identified on the basis of a high return on the near range side and shadows on the far range side. This high return shadow pattern is just the opposite of that produced by a linear depression such as an arroyo (Figure B-2). Some of the mountains east of Phoenix appear to be high enough to support trees of some type; however, no vegetation patterns are discernible, probably a function of the coarseness of resolution.

Figure B-2. High return - shadow zone relationship of elevated and depressed terrain elements.

In the city of Phoenix, some of the residential neighborhoods appear to have numerous trees as well as some city parks. Neighborhoods with trees are most likely those areas in Phoenix of lesser radar return, the return being reduced by the destruction of the corner reflector effect of buildings.

Concealment

Because of the low, sparse vegetation in this area, concealment would be difficult. Only the tree lined arroyos mentioned in the section on vegetation offer the possibility of concealment in rural areas. The city itself offers possibilities for concealment, especially in older residential areas where trees may be established. Some degree of concealment may be achieved in the narrow canyons of the mountainous areas and in the deeper arroyos of the alluvial fans. However, these areas would not be safe from aerial observation. Because of the unconsolidated nature of the surface material in this region, foxholes could be constructed quite easily and in a short time, in all areas except the mountainous areas, where bedrock outcrops are very close to the surface. Rock is available in those areas for making body shelters.

Cross Country Movement

Movement of troops would be restricted to streets in urban areas. Movement in the agricultural areas of the alluvial plains would be aided by the numerous section roads; however, cross country movement would be hampered by numerous wire fences and small irrigation ditches; larger ditches and canals would be major obstacles. Low relief areas on alluvial fans allow for easy cross country troop movement. However, where arroyos are more deeply entrenched, ease of movement may become highly directional in nature. Movement up or down the alluvial fan may be quite easy with troops travelling on the firm level divides between adjacent arroyos or in the sandy arroyos themselves where they are afforded some degree of concealment. However, movement at right angles to the prevailing drainage entails continual climbing in and out of arroyos and would also restrict the movement of supporting armor. The steep slopes and deep arroyos of the mountains would make cross country troop movement difficult

Cross country movement of vehicles would be constrained by many of the same factors affecting troop movement. Existing streets and roads in urban and agricultural areas would aid movement, and the primary obstacles to cross country movement

throughout the alluvial plains would be irrigation canals and ditches. Movement of vehicles across alluvial fans that lack dissection should be unrestrained on gentle slopes, although vehicles may find the loose pavements of the alluvial fans difficult to traverse even on moderate slopes. Loose sand that clogs many of the dry washes could hinder the movement of wheeled vehicles. In areas of dissection, movement of vehicles would be restricted to the level divides between arroyos and in directions parallel to the prevailing drainage pattern. The interfluves provide a firmer foundation than the arroyos, however, and they may support a more uniform stand of vegetation. The complex of plants and shrubs on the fans should not stop vehicles with relatively high clearance. Movement in the arroyos may be possible; however, large amounts of uncompacted sand could slow or even halt vehicular movement. In addition, phreatophytic trees could totally block arroyos in areas where the water table is near the surface.

Conclusions

The degradation of detail in this coarse resolution imagery has resulted in the loss of considerable data in the urban area. The major transportation network is well defined and commercial and residential areas are easily delineated. However, with improvement of resolution and dynamic range, better definition of streets would be realized, and better delineation of building type in both residential and industrial areas could be achieved. With improvement in resolution, the change in characteristic appearance of the power line from near to far range, and of the power line oriented parallel to the flight line in the far range, would be largely eliminated, particularly with the utilization of a synthetic aperture system. In addition, plant communities could be better defined. It should be noted that the isolated hills within the urbanized area in the northeast quadrant of the city show minimal shadowing in the near range and increasing shadowing as range is increased in the upper image. Inasmuch as local incidence angle is the significant factor in determining the intensity of return from a particular area, look direction becomes as significant in analyzing natural terrain surfaces as it is in analyzing the urbanized area. There is, for example, a significant variance in return from the older alluvial fans with a change in look direction and depression angle (Plate III, OF). By comparing the intensity of return from a single slope on two images with different look directions, and with a knowledge of depression angles, an interpreter should have

sufficient data to make at least a qualitative or semi-quantitative estimate of slope. It should also be noted that in an area of high relief, in order to obtain total coverage, a second look or an increase in depression angle is essential (Figure B-3). In planning tactical terrain data acquisition, therefore, areas which require more than one look direction for adequate analysis should be specified. A capability for acquiring a variety of look directions in a single pass with a steerable array antenna should be highly useful.

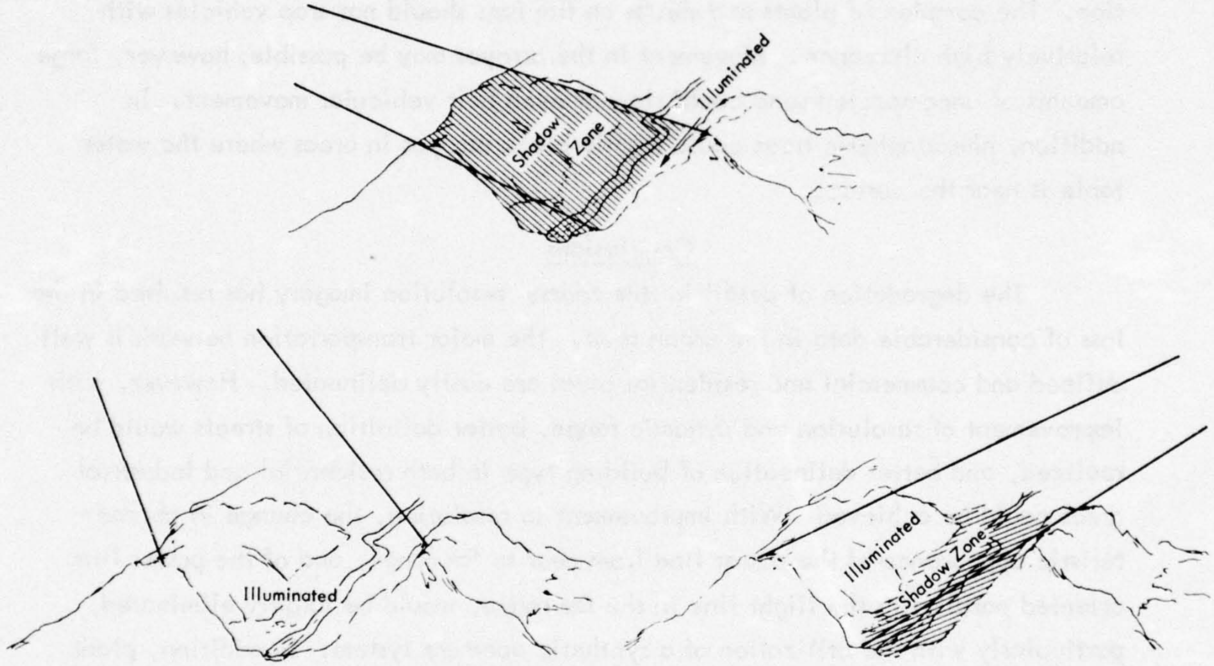

Figure B-3. Methods for Elimination of Shadow Zones in High Relief Terrain

Despite limitations discussed, this operational Army radar can produce a wealth of regional terrain data in an area of desert basins and plains, interspersed with isolated rugged mountains. Particularly important in collection of regional terrain data is the wide swath-width capability of the system.

APPENDIX C
ATRATO DELTA, GULF OF URABA, NORTHWESTERN COLOMBIA
(Plate IV)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Resolution(m) Across track	Swath(km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7xR_{km}$	9	10-20	HH and HV

Terrain and Cover Characteristics

Identification of plant communities *per se* cannot be achieved from radar imagery alone. However, separation of communities because of variations in leaf, trunk, or stem geometry, moisture content, canopy configuration, and density can be realized directly from the imagery. With a knowledge of the environment and the distribution of the various possible assemblages as related to terrain, vegetation patterns can be identified and other relevant terrain characteristics can be deduced.

Using aerial photographs as a base for surface mapping, Vann (1959)[10] isolated five major floral assemblages (Figure C-1) and related them to terrain types in the Atrato Delta. These five major vegetation types,

> "serve to differentiate terrain types in the delta and are especially valuable as photo interpretation (radar) keys." "The chief significance of the vegetation of the Atrato Delta to the alluvial morphologist is its value as an indicator of terrain types. Everywhere mangrove occupies the mud flats of the tidal zone, the pangana community clothes the levees, the point bar assemblage marks areas of stagnant or weakly circulating fresh water, and the grass and sedge and palm communities occur in the backswamps."

Contrasts in vegetation and canopy height aid both in isolation of the communities and consequent identification of terrain types on radar imagery.

Mangrove - Mangrove canopy ranging from 20-30' high.

Pangana - Dominated by palms but including a mimosa type and the Guinea chestnut, both of which range up to 50' high.

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10 Vann, J.H., "Landform-Vegetation Relationships in the Atrato Delta," Annals of the Association of American Geographers, vol. 49, no. 4, pp. 345-360, December 1959.

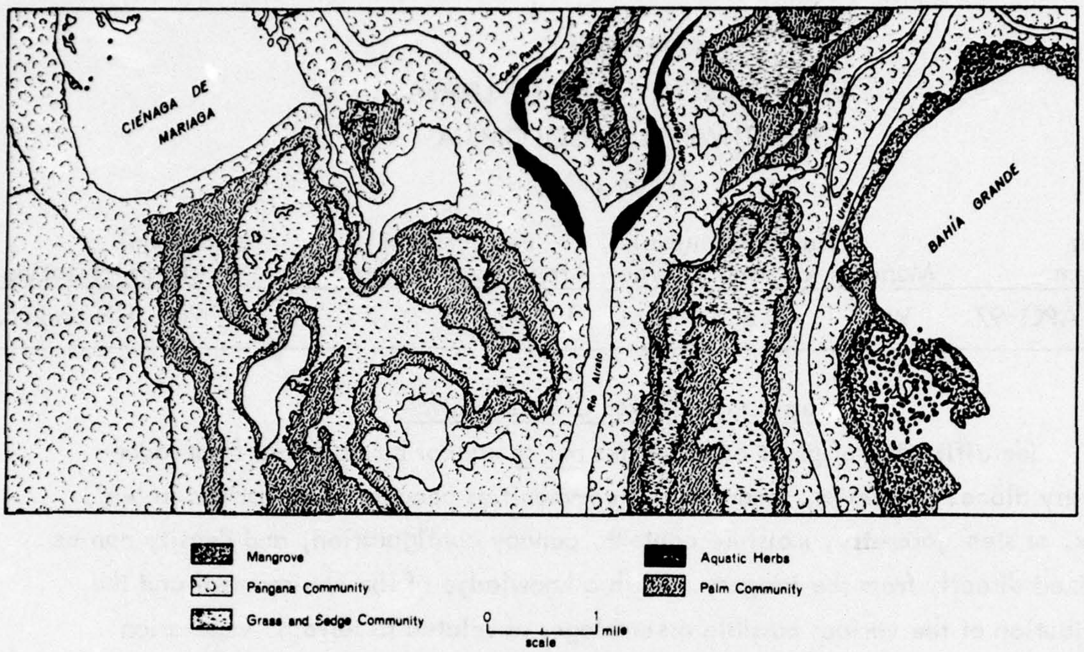

Figure C-1. Vegetation Patterns in the Atrato Delta as Mapped by Vann (1959)[11]

Palm	-	**A variety of palms forming a canopy lower than that of the pangana community.**
Grass & Sedge	-	**A low growth of grasses and spiny shrubs.**
Point bar	-	**Low growth habit aquatics forming a mat in a deteriorating channel.**

The Atrato is characterized by great flutuation of volume in its lower course. The nature of changes in a delta must be considered in a comparison of Vann's vegetation map (prepared from patterns observed in 1954) and radar imagery produced approximately 13 years later. For example, the area identified as aquatic herbs apparently has silted up to the point that the levee is now developing over this area and consequently the pangana community is taking over.

<u>Results of Analyses (Plate IV, Overlay)</u>

The region surrounding the Atrato Delta in Northwestern Colombia offers an excellent opportunity for the demonstration of capability of SLAR for the collection of vegetation data and the isolation of plant communities. Unfortunately, the imagery

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11 Vann, J. H., <u>op. cit</u>.

is of relatively coarse resolution. Resolution from the interpreter's point of view might best be viewed as the ability of the radar to isolate two similar objects separated in distance by the resolution figure. Thus, resolution of 9 meters would mean that two similar objects separated by a distance in excess of 9 meters would appear as separate entities. It might also be considered in terms of the minimal size of a particular object, for if detectable and less than the resolution in size it will in fact fill the resolution cell and appear to be larger. Viewed either way, a resolution of 9 meters in the along track direction and $1.7 \times R_{km}$ in the cross track direction is relatively coarse for the derivation of vegetation (tree size, canopy density, etc.) and other military terrain data.

Vegetation Types

Regardless of the restrictions imposed by the relative coarseness of the resolution, considerable data regarding vegetation and concealment have been revealed. Basic vegetation types and their capabilities for concealment are defined with relative ease on each of the images: (Plate IV, Overlay)

Area 1	Tall forest of emergents with discontinuous canopy located in uplands, capable of concealing large numbers of men, less than a 50% possibility of concealing heavy equipment.
Area 2	Tall forest with no emergents and a continuous canopy located in foothills belt, capable of concealing both men and equipment.
Area 3	Open woodlands with a discontinuous canopy, tall herbaceous vegetation and grasses, incapable of concealing large numbers of men or equipment but could provide concealment for small groups.
Area 4	Tall forest with few emergents located on natural levees, capable of concealment of several platoons of foot troops, sufficiently discontinuous to provide little concealment for equipment.
Area 5	Forest of tall mangroves standing in water, localized in extent, would only provide concealment for a small number of men.
Area 6	Open woodland with a discontinuous canopy, little herbaceous vegetation in the understory, little opportunity for concealment of vehicles but adequate capability for concealment of a company of foot troops.

Only the mangrove community has been positively identified. For lack of knowledge of tropical vegetation, the interpreter has differentiated the other vegetation types without classifying them. The same difficulty would be present if an aerial photo of an unfamiliar area was analyzed. Much or perhaps more depends on the interpreter's knowledge of regional conditions and practices than on radar system and interpretation principles.

In addition to being an outstanding example of the isolation of plant communities on the basis of relatively sharp tone and textural contrast, this demonstration emphasizes the importance of depression angle. Particularly striking is the strong contrast between communities in the near range and the importance of shadowing in the middle to far range, particularly where the mangroves stand along the near range side of a lower pangana community and sharply delineate the contact with shadow zone.

The strong tonal and textural contrasts in the vegetation communities in the Atrato delta can be further emphasized by level slicing and color assignment utilizing the IDECS system (Figures C-2,3). Such a display not only emphasizes the contrast in plant communities but also enables the interpreter to quickly isolate those areas with which he is primarily concerned.

<u>Surface Configuration</u>

With the exception of the mountainous area marginal to the delta, this is basically an area of lowlands with little contrast in topographic relief. Conclusions relative to the configuration of the surface, in such an area, depend largely upon the interpreter's understanding of deltaic sedimentational and erosional processes:

Area 1 & 2	Broken upland area, locally with high relief, covered by discontinuous forest.
Area 3	Relatively level lowland area covered by discontinuous forest and subject to periodic flooding.
Area 4	Natural levees 7-15 feet above the adjacent land surface, covered with tall vegetation.
Area 5	Beach and near shore area of tall trees with submerged root systems.
Area 6	Flat coastal lowlands with medium height open woodlands.
S	Streams
W	Inland open areas of standing water.

Figure C-2

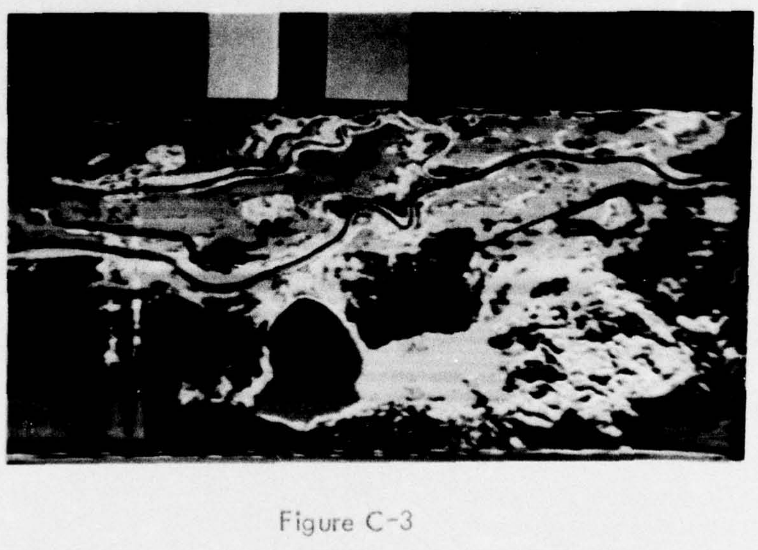

Figure C-3

Figures C-2, -3. Level slicing and color coding of vegetation communities in the Atrato Delta utilizing the IDECS system. Green is open water and colors above each image are arranged right to left representing increasingly dense stands of forest.

Soil Type and Depth

These data are derived through inference; no soil information is directly revealed in the radar imagery. With the knowledge of soil forming processes in the tropical region, classification of soil and thickness of soil can be based on the characteristics of the local terrain:

Area 1	Alluvium greater than 20 feet thick.
Area 2	Pediment soils, 10 to 20 feet thick.
Area 3	Foot hills soil, 5 to 10 feet thick.
Area 4	Mountain soil, less than 5 feet thick.

Offshore Features

Although little can be seen in the way of offshore characteristics, some data can be derived which are important from the military point of view. Easily identified offshore features are:

Area 5	Mangrove forests, tree roots in standing water.
Area 6	Unconsolidated deep alluvium in near shore delta.
Area 7	An offshore spit.
Area 8	Waves breaking along shore.

The presentation of some of the above features is highly dependent upon range. Features related to tidal zones such as mud flats, shell bars or reefs are much more vividly expressed in the near range than they are in the far range. In fact, fall-off in the far range is often sufficiently great to preclude their appearance (Hanson and Dellwig, 1973).[12] This is true whether the expression of such features is due to breaking waves or emergent flats. Although none of these features are direct indications of water depth, the identification of mud flats, shell bars, surf zones and offshore reefs gives the interpreter data from which he can draw at least qualitative conclusions concerning water depth and bottom conditions in the near shore zone, these data being essential for over-the-shore operations planning.

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12 Hanson, B.C. and L. F. Dellwig, "Radar Signal Return from Near-Shore Surface and Shallow Subsurface Features, Darien Province, Panama," Proc. 1973 ASP/ACSM Fall Convention, Orlando, Florida, October 1973, pp. 1017-1031.

Cross Country Movement

As in the determination of soil types and depth and in the configuration of the surface, a great deal of the data concerning movement of foot troops or vehicles through such an area is dependent on the interpreter's knowledge of terrain modification processes and vegetation in the tropical environment.

Area 1	Moderately difficult for foot troop movement, capable of supporting vehicles only during the dry season.
Area 2	Moderately difficult for foot troops during the dry season, very difficult for movement of foot troops during the wet season, extremely difficult for movement of vehicles at all times due to vegetation.
Area 3	Very difficult for both foot troops and vehicles at all times due to the density of vegetation.
Area 4	Very difficult for foot troops, extremely difficult for vehicles due to the presence of water and large trees growing in the water offshore.
Area 5	Extremely difficult for foot soldiers, and impossible for vehicular movement due to heavy vegetation and high local relief.

Conclusions

Although hampered by coarseness of resolution which does not permit accurate determination of the percentage of terrain covered by canopy, coarse resolution radars are sufficiently adequate for the isolation and, with corroborative data, identification of plant communities. From such data, along with a knowledge of regional characteristics and processes, a great deal of significant terrain data can be extracted. The information extracted has military value of tactical utility in the production of factor maps such as for cross-country mobility and concealment, etc. This is a clear demonstration of the tactical value of SLAR in a worst-case situation in which cloud cover in an area of extremely dense vegetation would have denied observation by any other sensor.

Results of Analysis (Plate V, Overlay)

Man-Made Features

As mentioned previously, winter imagery appears better suited for mapping man-made features because of the suppression of ground return. Buildings, roads, railraods and power lines all stand out better on winter imagery. Wire fences which are nearly indistinguishable on spring imagery are very apparent on winter imagery. One feature which appears better on spring imagery is an airport. The low return from the paved runways contrasts with the brighter return from the surrounding grass covered areas. On winter imagery, however, these same low returns blend in with surrounding low returns of dormant grasses.

Surface Configuration

Six surface configuration regions were mapped from the spring imagery of the region between Colorado Springs and Denver.

Rolling Plains (RP) -- This type of topography lies east of the mountains and between upland areas. It is composed of very gently rolling hills and plains with very little local relief. Divides are rounded and not very distinct. Drainage is complete and dendritic in pattern. This type of topography is dominated by grassland, but includes most of the cropland mapped in the area and some of the forests.

Table Lands (T) -- To the south of Denver a large plateau is capped by a nearly horizontal resistant rock unit. The plateau is surrounded on most sides by a steep escarpment but merges with the gently rolling plains to the south. This plateau has very little relif on top and moderate relief along the escarpment where numerous canyons have been incised.

Isolated Buttes and Mesas (BM) -- Closely associated with the table lands lying to the south are numerous buttes and small mesas which are capped with the same resistant unit that caps the table land. The buttes and mesas are generally small in area, level, and surrounded by slopes which are near vertical at the edge of the buttes and mesas and uniformly decrease in slope to their junction with the rolling plains.

Dissected Uplands (DU) -- A large area between the table lands and the mountain front has been mapped as dissected uplands. These areas stand topographically above the rolling plains that make up surrounding flatlands and the intervening

river valley but below the table lands. The dissected uplands have a much higher stream density than any other area, with sharp and well defined interfluves. Relief is on the order of 500 feet or less.

Hogbacks (H) -- Along the mountain front in some areas are steeply upturned sedimentary formations. The more resistant of the formations form narrow linear ridges which, except where breached by streams, are effective natural barriers. The formations responsible for these ridges dip to the east, thus the east slopes are relatively gentle dip slopes whereas the west slopes are rugged and steep, due to the outcropping cap rock.

Mountains (M) -- Along the western edge of the imagery lies a large mountainous area of very rugged terrain with relief in excess of several thousand feet. Drainage patterns are very apparent and can be quite easily mapped, as has been previously demonstrated by McCoy (1969)[15] among others.

Vegetation

Four vegetation types have been mapped in the study area. These include two forest types which were mapped from winter imagery and grassland and cropland which were separated on spring imagery. Because the flight lines of the two images were very nearly the same and because the scale is constant, the vegetation overlay can be matched to either image without a lack of congruency.

Forest (F1) -- This type of forest is a high dense type that appears to provide good cover. It has a fine texture and dark appearance on radar although not as dark as the surrounding grasslands and crops. An estimate of the height of the trees is gained by the bright edge of the forest on the near range side and by the length of shadow on the forest edges on the far range side. Improvement of resolution would permit measurement of tree height utilizing the similar triangle technique (Plate VI). It would further permit an estimate of crown size and spacing (both critical in the determination of the extent of cover offered by the vegetation), provided that the scene was not in a low depression angle region of the image (Figure D-1). This forest occurs throughout the mountainous area and also in an area in the plains north of Colorado Springs.

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15 McCoy, R.M., "Drainage Network Analysis with K-Band Radar Imagery," Geographic Review, vol. 59, p. 496, 1969.

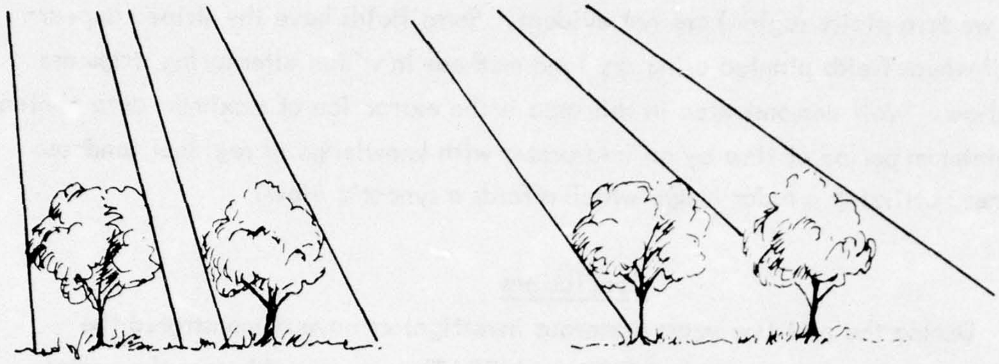


Figure D-1. Effect of depression angle on the determination of the crown size with fine resolution radar

Forest (F2) -- This forest type differs from type 1 on the imagery by being brighter in tone and coarser in texture. It occurs in areas along the mountain front, in the dissected uplands and along the scarps of the table lands and the buttes and mesas. It also occurs on some of the eroded slopes in the plains areas. Such areas consist of smaller and more widely spaced trees than the first type, as suggested by the lack of edge enhancement by the radar and by the coarser texture of the imagery. The canopy is not closed, therefore concealment would be difficult.

Grassland (G) -- Areas of non-forest can be easily mapped on the imagery, however, the breakdown into grassland and cropland can be accomplished only in the spring. Grassland areas appear as dark, very even-textured areas on radar imagery and occur in many areas of the plains and on top of some of the flat-topped mesas and table lands.

Cropland (C) -- Areas of cropland were mapped along the northern edge of the study where they merge with the suburbs of Denver. Croplands also exist along the eastern edge of the area. Croplands have a checkerboard appearance due to variations in growth stage and crop type in adjacent fields. Some fields, especially those containing small grain crops may be difficult to separate from adjacent grasslands. Similarly, ranching areas where grass types or grazing pressures vary from pasture to pasture may be confused with cropland. The cropland in this area appears to be unirrigated since irrigation ditches or pivotal sprinklers (typical irrigation methods

in the western plains region) are not evident. Some fields have the striped appearance of wheat fields planted using dry land methods in which alternating strips are left fallow. Well demonstrated in this area is the extraction of maximum data content in a minimum period of time by an interpreter with knowledge of regional land-use practices, utilizing a radar image which affords a synoptic view.

Conclusions

During the past few years numerous investigators have demonstrated the seasonal variation data content of ERTS (LANDSAT) imagery. Whereas the aerial camera or scanner in the visible portion of the spectrum is dependent upon color and textural contrasts for the expression of contrasts in terrain characteristics, radars are dependent upon surface configuration and dielectric properties. Thus, recorded seasonal changes in vegetated areas are effected by changes in leaf or crop geometry and moisture content, and in bare soil or rock areas by the same factors.

In the region between Denver and Colorado Springs, winter imagery is judged superior for separating forested from non-forested areas; however, in non-forested areas, spring imagery is better for separating cropland from grassland. Hard targets, lines of communication and wire fences are much more easily detected on winter imagery. However, in the areas east of the mountains, spring imagery is better for mapping surface configuration inasmuch as this imagery lacks the contrasting tones produced by higher vegetation which are apparent on the winter imagery and which are distracting from a topographic point of view. The mountainous areas have a similar appearance on both types of imagery.

The improved presentation of man-made features in winter, when vegetative contrasts are at a minimum, can also be achieved by setting the gain for maximum definition of man-made features, but at the expense of the degradation of contrasts in natural terrain features. Thus for optimum knowledge of terrain as well as target data, multiple season coverage is desirable. Obviously, had the area also been studied when snow-covered, additional differences would have emerged.

APPENDIX E

CONNECTICUT RIVER VALLEY - VERMONT AND NEW HAMPSHIRE

(Plate VI)

Radar System	Manuf.	Wavelength(mm) or Band	Type	Resolution(m) Along track	Across track	Swath(km) Width	Polarization
AN/APQ-97	W	8.6	Real	$1.7xR_{km}$	9	10-20	HH and HV

Terrain Characteristics

AN/APQ-97 radar imagery of a 30 mile long section of the Connecticut River Valley in Vermont and New Hampshire was selected for use in evaluationg SLAR imagery in an area with a cool, humid climate and supporting a mixed hardwood forest. The imagery was recording with a west look-direction and includes that portion of the Connecticut River Valley stretching downstream from just above Windsor, Vermont to just below Bellows Falls, Vermont. Also included in this area are the towns of Charlestown and Claremont, New Hampshire. The Connecticut River Valley is an important communication corridor connecting the highly industralized cities downstream with the northern portions of New England.

Results of Interpretation (Plate VI, Overlay)

Lines of Communication and Urban Patterns

Most of the communication lines mapped in the study area lie either in the valley or in close proximity to it. These include a divided highway, several roads, a power line, a railroad, and of course the river itself. A few other roads were mapped outside of the valley; however, there are doubtlessly additional roads that are not apparent on the imagery. Roads are best seen on the imagery of this area when they pass through heavily forested areas or areas devoid of trees. However, many of the roads appear to follow tree-lined stream valleys and direct identification of the roads is difficult. Likewise, agricultural areas are characterized by numerous tree-lined streams, woodlots and hedgerows, all of which shield roads from direct view. As an approximation, it can be assumed that larger stream valleys, such as those mapped, all contain roads.

Five urban areas have been mapped in the study area. Four of these are located along the Connecticut River and the fifth and largest is a few miles to the

east of the river. Business districts can be recognized in these towns by their bright returns which contrast with darker returns from surrounding residential areas. The southernmost town (Bellows Falls) is located at a dam which impounds the Connecticut River. Considerable industrial development can be recognized along the river downstream from the dam. The two power lines mapped in the study area appear to lead away from this dam suggesting that it may be a hydro-electric facility.

One municipal airport has been mapped near the town of Claremont which lies on the east side of the river. At least three bridges cross the Connecticut River, possibly four if the dam at Bellows Falls also serves as a bridge.

Surface Configuration

The Connecticut River flows south through the area, its course appearing to be structurally controlled. Smaller streams to the west of the river and in the northern third of the image also appear to be influenced by a north-south structural grain. The area is characterized by rounded hills and low mountains. Plate VI, Overlay, summarizes the topography of the area. Slopes were estimated by noting the depression angles responsible for producing shadows behind various hills. A slope which bears shadow is steeper than the depression angle at the top of the slope. This knowledge can then be extrapolated to other parts of the image.

Being in a mature stage of erosion, the area possesses a well developed drainage network. Thus the upland areas are cut by many stream valleys that would provide convenient transportation routes for both foot soldiers and vehicles. As previously mentioned, many of these valleys already possess roads. Travel in areas lying outside of stream valleys, through not severely restricted by topography could be hindered by vegetation.

Soils

Soils were classified into three general categories which are closely correlated with topography. Shallow, rocky soils exist in the uplands. Pleistocene glaciation has scoured these hills in the past, removing most of the pre-glacial soil. As a result, bedrock is very close to the surface, and soils that have developed since glaciation are quite rocky. Deeper fine-grained soils exist in the lowlands. These soils have been divided into two categories. Floodplain deposits exist in the narrow floodplains of the Connecticut River, and its tributaries; additional fine soils exist in terraces

and other flat-lying areas above the level of the floodplains. Some of these upland fine-grained soils may be developed on glacial deposits left by the retreating Pleistocene glaciers. The fine-grained soils support the bulk of the agricultural activity in the study area.

Vegetation

Vegetation has been divided into two categories, forest and non-forest. Forests are best developed in the hilly, rocky uplands. The lowlands and other areas of fine soil have been cleared and are now devoted primarily to agriculture. Interspersed in the agricultural areas with fields are numerous woodlots and hedgerows which separate adjacent fields in many instances. Thus the non-forested area, as mapped, is not totally without trees.

Concealment

Concealment in this area is seasonably dependent since the forests are composed primarily of deciduous hardwoods. In the summer and early fall, concealment would be quite easy. The forests appear to be very dense with closed canopies and should provide effective cover. Numerous opportunities for concealment also exist in non-forested areas where woodlots are numerous and conveniently spaced. Roads in the area are also well protected from view for the same reasons that they are difficult to identify: they follow wooded streams and hedgerows and many seem to be tree-lined themselves.

Conclusions

Deciduous hardwood forest can be easily mapped from radar imagery in this area and opportunities for concealment can be easily determined. As in other hilly and mountainous terrains, radar imagery of this region graphically portrays the topography. With a knowledge of the depression angles, it is also possible to make estimates of terrain slope. The topography, as expressed on radar imagery, can also be used to infer general soil type and estimates of soil depth. Towns and their business centers can be mapped as well as major lines of communication; however, secondary roads and highways are difficult to detect because of the dense vegetative cover.

APPENDIX F
PRINCIPLES OF RADAR IMAGING

Radar (Radio detection and ranging) is an active remote sensing system that supplies its own illumination. The transmitted energy is selectively returned from target to receiver and is subsequently recorded. SLAR utilizes a narrow beam of pulsed microwave energy which is transmitted out of the side of the aircraft; this beam is swept across the surface of the earth by the forward motion of the aircraft. The radar return signals within the narrow beam are recorded in simplest form on a photographic film to produce a strip map, which in many characteristics is similar to the aerial photograph.

Many variables in the design and operation of SLAR's influence the interaction between transmitted energy and terrain and the resulting return signal. Either real aperture antennas or synthetic apertures, developed from sequences of received and stored signals (SAR), may be used. With either system a narrow beam resolution, dynamic range, incidence angle, polarization and radar frequency may be subject to variation and influence the return signal to a greater or lesser degree.

Most radar systems operate in the microwave portion of the spectrum between about 0.3 cm and 300 cm wavelength; indeed, most present SLAR's operate between 0.8 and 3.5 cm wavelength. Because these wavelengths are much longer than those used by optical and infrared sensors, the radar is influenced by different terrain parameters, at least in scale, than those to which the human eye reacts. Radar signals, because of their wavelength, may come from materials slightly beneath the surface, and not from the surface alone. For vegetation, this means that the radar penetrates through many leaves and stalks so that the return signal is a composite of signals coming from the surfaces visible to the eye and signals from regions within the plant or beneath the vegetation canopy that would be invisible to a camera. For soil, this means that not only the surface roughness and electrical permittivity but the characteristics of the near subsoil govern the observed signal. When the vegetation is thin enough, or dry enough, or the wavelength is long enough, the return signal from a vegetated surface includes both vegetation effects and soil effects. The amount of this penetration depends on various factors; in general, however, the penetration increases with increasing wavelength and decreases with increasing moisture content. Thus, a one-cm radar images only the upper layers of a forest or a field of corn; a 30-cm radar images a combination of leaves and trunks in a forest and of leaves, stalks, and perhaps even soil in a cornfield. If the corn plants are dry, the 30-cm radar may image primarily

soil effects; if they (the plants) contain much moisture (as during the height of the growing season), even the 30-cm radar image may be primarily due to the plants themselves.

Imaging radars, like other remote sensors, depend on variations in the relative strength of the signal returned from different parts of the area imaged to produce contrasts, edges, and a range of image brightness that can be interpreted directly. The two primary factors determining the strength of the signal observed, and consequently the brightness of the image point, are geometry and dielectric properties.

In the microwave region the most important geometric effects are caused by the surface structure, measured in terms of the wavelength. Surfaces that would be very rough at optical wavelengths can be very smooth at centimeter wavelengths; but small surfaces, such as leaves, that appear smooth at optical wavelengths may be only a fraction of a wavelength across at centimeter wavelengths; so that they scatter incident illumination uniformly in all directions for radar, but specularly reflect light in only one direction. Furthermore, a plowed field may appear very rough at a wavelength of a centimeter, but quite smooth at a wavelength of a meter. Thus, the same field might appear either bright or dark on an optical image, bright on an image made with a one centimeter radar and dark on an image made with a one meter radar. Since trees always appear rough to a radar, they always appear bright on the image. Full understanding of these geometric effects is still the subject of considerable research because the geometry of many objects is quite complicated, but catalogs of radar responses are available to a limited extent and are being improved even while the research continues.

Dielectric properties determine whether a radar signal from a surface of a given geometry will be strong or weak relative to other signals from a surface with the same geometry. If the complex dielectric permittivity is large, the signal will be large, for less of the incident energy penetrates the surface and more of it is reradiated than would be the case if the permittivity were small. Most nonmetallic materials have relatively small permittivities in the dry state, but the permittivity of water is large. Consequently, the strength of the radar signal from soil or plant is strongly influenced by its moisture content. Although this effect exists to a limited degree with optical wavelengths, it is much more important at radar wavelengths. Metallic objects are usually very efficient radar reflectors.

All radar systems operate in a similar manner. A transmitter generates short bursts or pulses of radio frequency (RF) energy which are propagated into space in a direction normal to the flight path by means of a directional antenna (Figure 3, pg. 7). The RF energy is confined to illuminate the surface of the earth in a narrow path as shown in the figure. At any one instant, the area of the earth's surface illuminated by the transmitted pulse is limited in the range direction by the physical length of the transmitted pulse in space and in the azimuth direction by the beamwidth of the directional antenna. A short pulse permits resolving ground elements close together in the cross-track direction, but a long pulse would superimpose the signals from these same elements. The azimuth resolution is determined by the length of the antenna and by the wavelength. An antenna 1,000 wavelengths long produces a beamwidth of one-milliradian, which translates into an azimuth resolution of one-meter per kilometer of range. Where this resolution is inadequate, the effective length of the antenna can be increased and the resolution distance decreased by use of the "synthetic aperture" (SAR) technique. In SAR theory, the azimuth resolution at any range is just half the length of the actual antenna with synthetic aperture, so a two-meter-long antenna could provide a one-meter resolution even at a distance of hundreds of kilometers. This result is independent of wavelength used. In practice, however, this resolution is difficult to achieve because of instabilities both in the flight path and the system components. The radar's resolving power is thus a function of the size of the areas illuminated by the transmitted pulse.

Objects which are reflective to the RF energy will radiate back a fraction of the transmitted energy to the receiving antenna. The reflected energy from these objects (a,b,c,d) received by the antenna is amplified and coverted by the receiver to a video electrical signal. This video signal is a function of the reflected energy from these objects, and can be displayed by modulating the intensity of the beam of a cathode-ray tube (CRT) as the beam is swept across the face of the CRT. The displacement on the screen is made proportional to the range from the antenna to the reflecting object. If the ground point is close, the time for the signal to go out from the radar is small; if the ground point is far away, the time for the signal to travel to it and return is large. Thus, by separating the signals that come back soon after the pulse is transmitted from those returning later, the radar may distinguish

between near and far targets. This single line display may be recorded on photographic film. The resulting display will be similar to one line of a television picture of the earth's surface.

As the antenna is repositioned during flight to "look" at a new strip of the earth's surface adjacent to the one previously imaged, another pulse of RF energy is transmitted and the returns are displayed on the CRT. Thus, another "TV line" will be generated. In operation, photographic film is moved past the CRT display line at a velocity proportional to the velocity of the aircraft. Thus, an image of the terrain illuminated by the transmitted RF pulses, as the antenna beam is scanned along the earth's surface will be built up along the film; just as a complete TV picture is built up by the individual lines of the TV raster. At least one radar system records the signal temporarily as a raster on a storage tube, which is then read out onto an actual TV monitor for viewing and photographing.

APPENDIX G

BASIC PRINCIPLE OF RADAR IMAGE INTERPRETATION

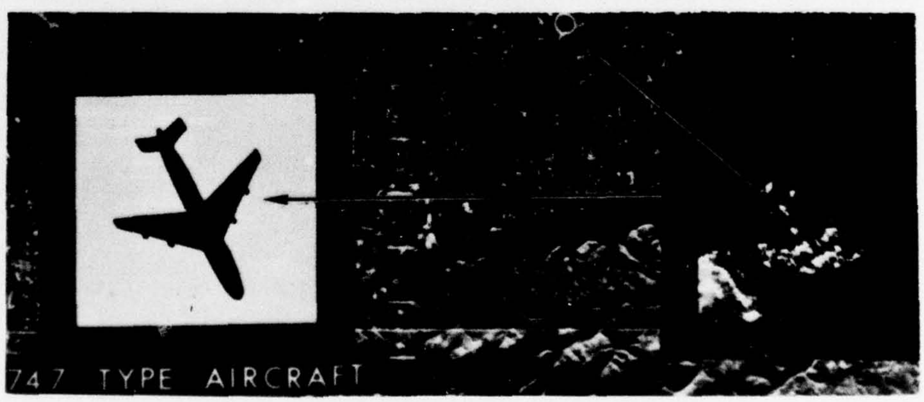
The radar image presents in the visible spectrum, an image generated in the microwave portion of the spectrum. By representing the microwave reflectivity characteristics of objects on the terrain but displaying them in a visual format, misinterpretation of radar images may occur. However, the very fact that the objects do appear different in the radar may be the source of additional unique information.

Shape and Pattern

In the interpretation of medium or large scale photographic images, the configuration of objects in terms of planimetric geometry are primary factors in their analysis. Individual objects within the scene are expressed in terms of differences in configuration, i.e., object A is round, object B is square, therefore object A is not object B. This reliance on shape is reinforced in large or medium scale aerial photographs by the objects' familiarity to the interpreter. In aerial photographs, these objects retain their natural shapes, thus the individual scene units are recognizable in themselves. Individual scene units are the basic units perceived by an interpreter which, when aggregated, comprise a scene. For instance, a building, a smokestack, a cooling tower and a transformer yard are individual scene units which when aggregated are a power station. With coarse resolution SLAR, the basic scene unit may lose its shape, and consequently its object context, because of resolution and backscattering properties of the individual scene objects. In real-aperture systems the resolving power decreases across-track from near to far range, while remaining constant along-track. In synthetic aperture systems there is (in theory) no degradation of resolving power from near to far range. As resolution improves, identification by shape becomes more feasible. For example, in the image of Dulles (Washington) Airport (Figure G-1) (AN/APQ-97 imagery, along-track resolution-1.7 m x range in kilometers, cross-track resolution-9 m) aircraft are seen only as shapeless spots of high return; whereas in the image of San Francisco Airport (Figure G-2) (AN/UPD-4 imagery, resolution-2.9 m) the aircraft can be identified and its dimensions determined with a reasonable degree of accuracy. Thus, in interpretation of coarse imagery one must rely more heavily on pattern and context than on shape when viewing relatively small objects.

AN/APQ-97

Figure G-1
Dulles International Airport, Washington, D. C.



AN/UPD-4

Figure G-2
San Francisco, California

Pattern is the repetitive spacing of units which, in combination, help identify the scene. A photographed scene may be inferentially identified through a known pattern, i.e., the regular spacing of houses, roads, yards and cars can lead to numerous inferences about suburbs. In SLAR, changes in patterns may be critical to discriminate one region from another, regardless of whether the imaged area is natural or cultural.

Size (Image Geometry)

Radar, a ranging device, records objects with respect to distance between the energy source and the terrain feature. Thus in the slant range format, recording range (distance) rather than angular relationships produces a continuous scale change, with image compression being greatest in the near range and minimal in the far range (Figure G-3). Thus terrain parameters such as length, shape and geometric orientation are often distorted when presented. Accurate planimetric measurements are complicated by the scale distortions inherent in slant range imagery.

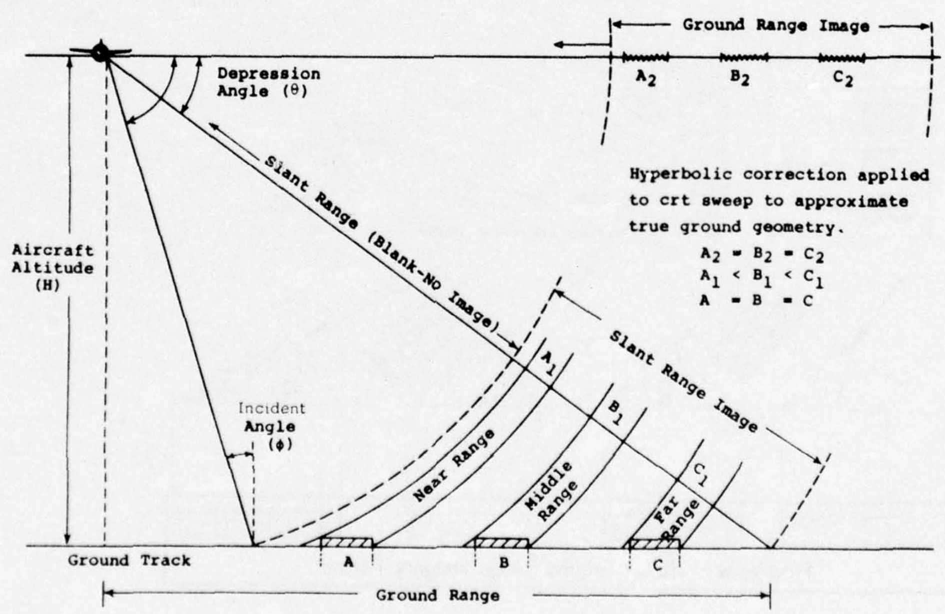


Figure G-3

Ground range - slant range comparative geometry

Because the slant distance from an elevated radar to a point on the ground is not the same as the horizontal distance along the ground from the point beneath the radar to the target point, distortions occur in the radar image. The scales for slant range and ground distance are about the same at angles of incidence near grazing, but the ground distance represented by a given increment in slant range increases rapidly as the beam approaches vertical. For flat terrain this effect may be removed electronically by use of the "true-ground-range" presentation. Unfortunately the TGR presentation is only "true" if no elevation differences exist in the terrain; when relief is high, the resulting parallax distortion is worse for TGR than for slant-range presentation.

For an object above a datum plane, radar relief displacement is toward the nadir, but if the object is below the datum plane, displacement is away from the nadir. This is opposite to the effect observed for optical systems. As illustrated (Figure G-4), if the base of the feature is imaged before the top,

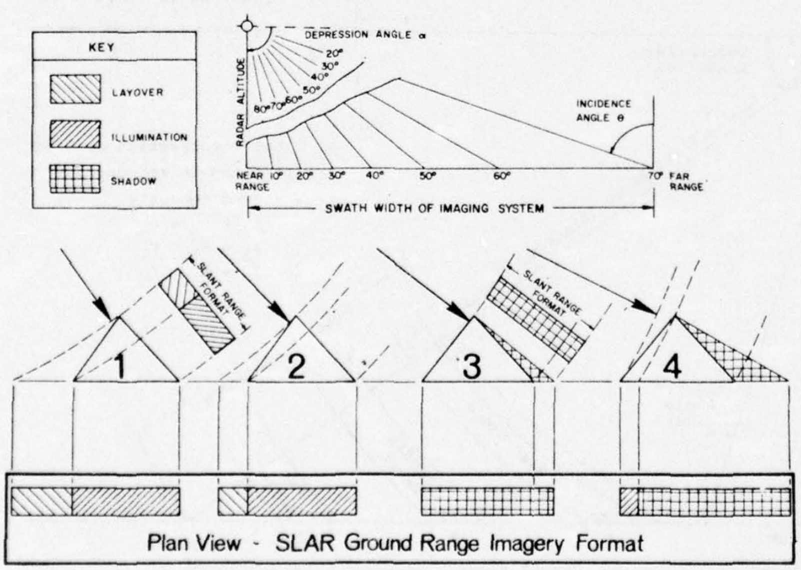


Figure G-4

Dependence of layover, illumination and shadow on depression angle

the slope appears compressed (foreshortened) in the image (Figure G-4, Feature 4). Accordingly, the amount of foreshortening is determined by the period of time a slope is illuminated, thereby determining the length of that slope displayed on the radar image. In the extreme case of the near range, the wave front reaches the top of the feature before the bottom; the top is recorded in a nearer range position than the bottom, hence the top is laid over the bottom (layover, Figure G-4, Features 1 and 2).

Whereas in the near range (Figure G-4, Features 1 and 2) the back slope of an object may be illuminated and recorded, in the far range the same backslope may give no return at all, (Figure G-4, Features 3 and 4) and adjacent terrain may also be blocked from illumination by the transmitted signal. Thus, there is no data record (radar shadow, i.e., black) of that zone on the image. This effect becomes increasingly significant as relief increases in an area and increasingly significant also as any given area of high-relief is moved from the near to the far range on the image. Geometric fidelity refers to the accuracy at which an imaging radar reproduces the spacial distribution of surface features it has imaged. In terms of the preceding discussion, distortions due to layover and foreshortening and therefore relief displacement for areas of very low relief is negligible when compared to the scale of the image; thus the geometric fidelity is at an optimum.

Length, width, area and volume of basic scene objects measured on SLAR imagery are difficult to determine at high depression angles because of image obliquity and displacement; however, in the middle to far range and at lower depression angles, corrections can be made relatively easy, and mensuration is feasible. This is particularly true when the objects are sizeable enough to exceed systems resolution. For example, in tests conducted by the U.S. Army, AN/APQ-102 imagery provided high enough geometric fidelity for small scale mapping (U.S. Army Engineer, Geodesy and Mapping Research and Development Agency, 1965).[16] Furthermore, measurements in fields ranging in size from 10 to 160 acres in western Kansas using SLAR (X-band Michigan system) and aerial photography (RC-8) showed no statistically significant difference between the 36 selected fields measured on

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[16] U.S. Army Engineer, Geodesy, Intelligence and Mapping Research and Development Agency, "Preliminary Determination of Geometric Capabilities of AN/APQ-102 Radar Presentation (U), unpublished, February 9, 1965.

radar images and aerial photographs (Coiner and Dellwig, 1972).[17] Within the context of regional analysis, the two independent experiments cited above point to SLAR's potential as another source of measurement data.

Mensuration (Frontispiece)

Accurate measurements on imagery are frequently essential to reliable intelligence productions. Although radar imagery poses different problems of measurement than aerial photography, techniques can be and have been developed which will permit relatively accurate horizontal and vertical measurements. The only effective technique of elevation determination over a large area, the interferometer technique, was first utilized in Panama and resulted in the development of a topographic map over the entire 10,000 square miles of Darien Province. With this technique an antenna and receiving channel is required in addition to the one used to produce the normal radar image. The second antenna is usually located parallel to the first, but separated vertically from it. At specific angles, determined by the number of wavelengths separating the antennas, the two radio-frequency signals received from the same ground element are 180° out of phase with each other, so that an image produced by adding these two signals before detecting them contains nulls (regions of zero output) at the specific angles. The 180° phase difference occurs because the path lengths from target to the two antennas differ by an odd multiple of a half wavelength. Since the antennas are spaced many wavelengths apart, each image contains several such nulls, each representing the angle where the path difference to the two antennas is a different number of half wavelengths. The resulting image with multiple null lines is illustrated in Figure G-5. Because each null corresponds with a particular exact depression angle, its position in the image contains two pieces of information, the slant range and the angle. With proper interpretation, these two items of information can be converted into two other items necessary for the topographic location of the point: the across-track ground range and the elevation of the point above a datum.

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17 Coiner, J.C. and L.F. Dellwig, "Similarities and Differences in the Interpretation of Air Photos and SLAR Imagery," Proc. Electro-Optical Systems Design Conference, New York, New York, pp. 89-94, September 1972.

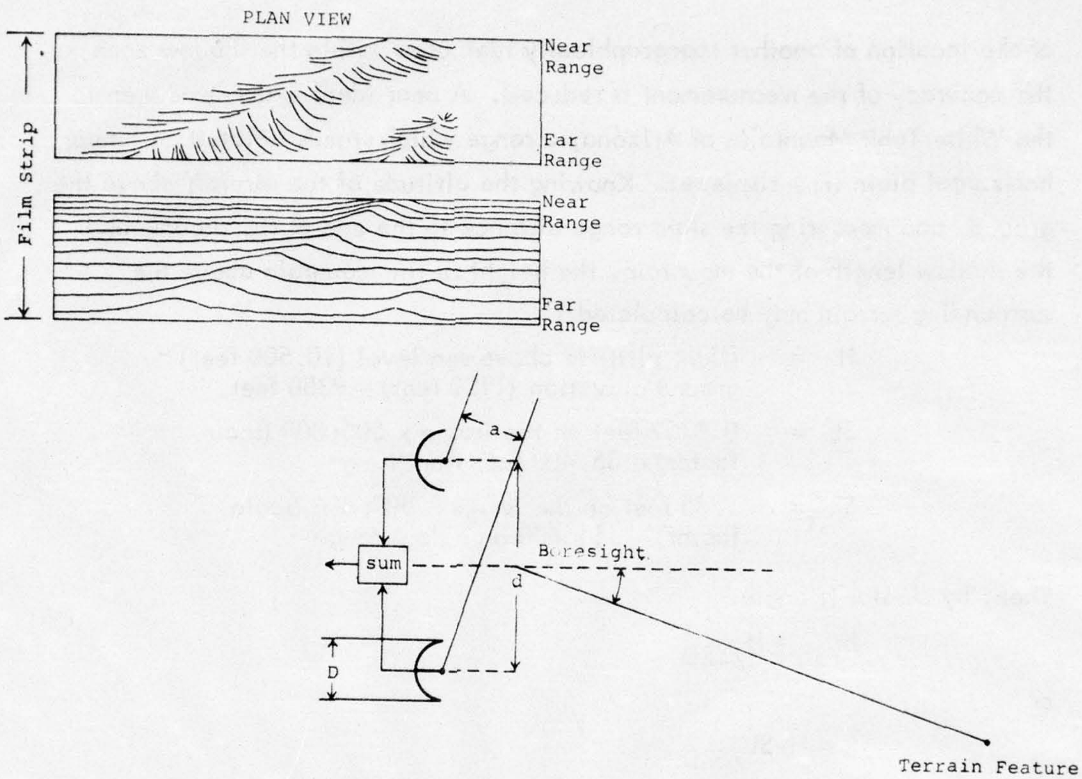

Figure G-5
Radar Topographic Mapping. Interferometric Model.

Elevation and ground measurements can be made from imagery alone. Whether the format be ground or slant range, knowing the height of the aircraft above the ground and the depression angle at the point for which the elevation is to be determined, elevations can be calculated, their accuracy depending upon the nature of the terrain surrounding the point for which the elevation is to be measured. Accuracy of determination utilizing the similar triangle technique (LaPrade and Leonardo, 1969)[18] is at an optimum when an isolated topographic feature is situated on a relatively flat plain. Accuracy of this technique is dependent upon the measurement of the shadow, a knowledge of the depression angle (less accurate than the knowledge obtained at an interferometer null) and the height of the aircraft. If the length of the shadow appears reduced because of the slope of the terrain surface toward the mountain in the far range or because

18 LaPrade, G.L. and E.S. Leonardo, "Elevations from Radar Imagery," Photogrammetric Engineering, vol. 35, no. 4, pp. 366-371, April 1969.

of the location of another topographically high area within the shadow zone, the accuracy of the measurement is reduced. A near ideal example is seen in the White Tank Mountains of Arizona, a range which stands isolated on a near horizontal plain (Frontispiece). Knowing the altitude of the aircraft above the ground, and measuring the slant range distance to the end of the shadow and the shadow length of the mountain, the height of the mountain above the surrounding terrain may be calculated:1

H = flight altitude above sea level (10,500 feet) - ground elevation (1120 feet) = 9380 feet.

SL = 0.0709 feet on the image x 500,000 (scale factor) = 35,400 feet slant range.

SRD= .275 feet on the image x 500,000 (scale factor) = 114,600 feet slant range

Then, by similar triangles

$$^{h}/_{SL} = {}^{H}/_{SRD}$$

or

$$h = {}^{H \cdot SL}/_{SRD}$$

substituting,

$$h = \frac{9380' \, (35,400')}{114,600}$$

$$h = 2897' \text{ above terrain}$$

Mountain Elevation = h + elevation of surrounding terrain

$$= 2897 + 1120 = 4017$$

This process may be simplified by the use of nomograms developed by Rydstrom (1968)[19] for slant range imagery and by Hanson and Yukler (1975)[20] for ground range imagery.

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19 Rydstrom, H.O., "Radargrammetric Applications of the Right Triangle Solution Nomogram," Goodyear Aerospace Corporation, Litchfield Park, Arizona, 1968, 23 pp.

20 Hanson, B. and A. Yukler, "Geometric Fidelity Levels Inherent to All Ground Range Radar Imaging Systems," RSL Technical Report 177-54, University of Kansas Center for Research, Inc., Lawrence, Kansas, July 1975.

Ground Measurement

In coarse resolution imagery, object detection may be realized whereas identification may only be on the basis of the position or relationship of the object in the scene. For example, a point of high return may be identified on an airport runway and would be assumed to be an airplane although no shape would be detectable. As resolution increases, identification on the basis of shape not only becomes feasible but measurements may be made (Frontispiece). Not only is the jet transport identifiable on the basis of its shape but length and wing span have been measured on this ten foot resolution imagery (Goodyear Aerospace Corporation, 1975)[21]. In the same scene an aircraft carrier was also identified, its length measured at 960 feet as compared to an actual length of 979 feet and its flight deck width measured at 225 feet with an actual width of 222 feet. In these examples the importance of fine resolution for the identification of man-made objects is strikingly demonstrated.

Distance measurements are most accurate in relatively flat terrain. As relief increases, distortion due to foreshortening and layover induce error into measurements particularly those made in a cross-track direction. However, if one can assume the availability of cartographic data, correlation of features on radar imagery and on a base map can be easily realized with measurements being made from the base rather than from the image itself. Imagery in the slant range format poses an additional problem (Figure G-6) in the near range compression. As is indicated, this distortion loses its significance in the far range and reasonably accurate measurements in relatively low relief country can be achieved.

Tone and Texture

For imaging sensors, tone is the degree of color (or blackness and whiteness) which, when varied over an area, provides information about the scene being imaged. It is the basic unit of interpretation; however, tone is highly sensor-dependent. For aerial cameras/film, the tone is a qualitative expression of the sun's reflected and scattered energy from about 0.3 - 0.8 nm. For SLAR imagers, the tone is the relative backscatter of emitted microwave energy, the wavelength

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21 Goodyear Aerospace Corporation, Synthetic Aperture Radar Imagery and Its Applications, GIB-9282D, Litchfield Park, Arizona, March 1975, 40 pp.

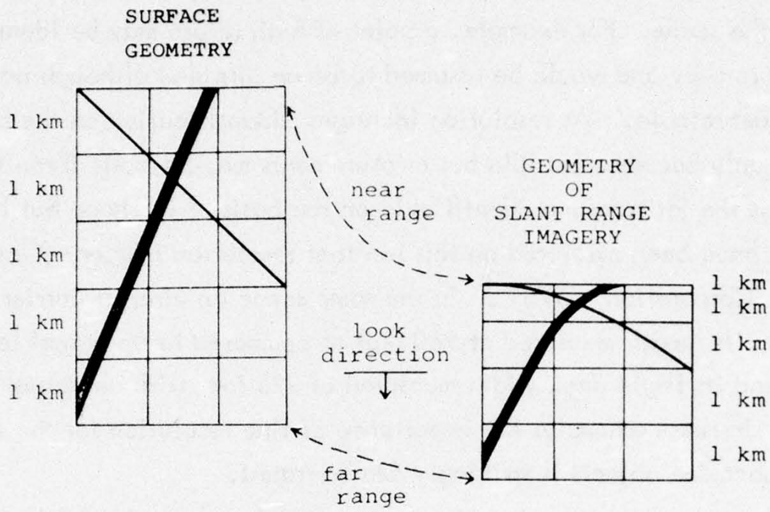

Figure G-6

Slant and ground range image geometry of a planar scene

of which can vary by system from 0.1 to approximately 100 cm. Tonal variations can also be a function of radar gain, contrast control and receiver linearity, as well as photographic processing of imagery. Texture may be defined as a regular variance in the way a surface is imaged. In both the interpretation of air photos and SLAR imagery, area-extensive phenomena can be interpreted from texture. Texture, both in the SLAR imagery (backscatter dependent), and airphotos (reflectance dependent) is extremely difficult to quantify.

The radar image presents in the visible spectrum, an image generated in the microwave portion of the spectrum. By representing the reflectivity characteristics of objects on the terrain by microwave frequencies but displayed in a visual format, misinterpretation of images generated with microwave frequencies may occur.

However, the very fact that the objects do appear different in the radar image may be the source of additional unique information.

The local angle of incidence, θ, is the angle formed between an impinging beam of radar energy and a line drawn perpendicular to the imaged surface at the point of incidence (Figure G-7). The angle between a line from the transmitter

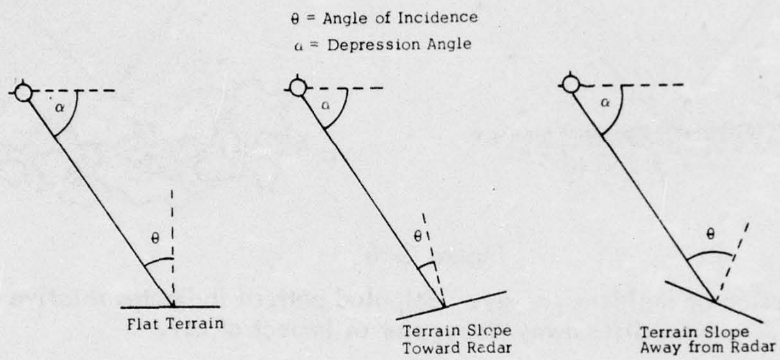

Figure G-7
Local angle of incidence

to a point on the terrain, and a horizontal plane passing through the transmitter is the depression angle (α). The geometric parameters of radar imaging systems are such that on flat terrain along the swath width of an area imaged (near to far range), there is a continuous change in the angle of incidence from a maximum at far range to a minimum, near normal incidence, in the near range. This relationship is modified with the introduction of a slope to the surface.

The energy incident on the terrain surface is "specularly" and "diffusely" reflected in varying proportions depending upon the roughness of the terrain. Surface roughness is a geometric property of the terrain; for radar, not absolute roughness, but rather roughness expressed relative to wavelength units is most significant. Surfaces with microrelief much less than a wavelength appear smooth (no return) whereas surfaces with microrelief on the order of wavelength or more, appear "rough". A smooth surface is characterized by nearly specular or mirror-like reflection with the angle of incidence determining the orientation of the reradiation pattern (Figure G-8). Thus, for a relatively smooth horizontal

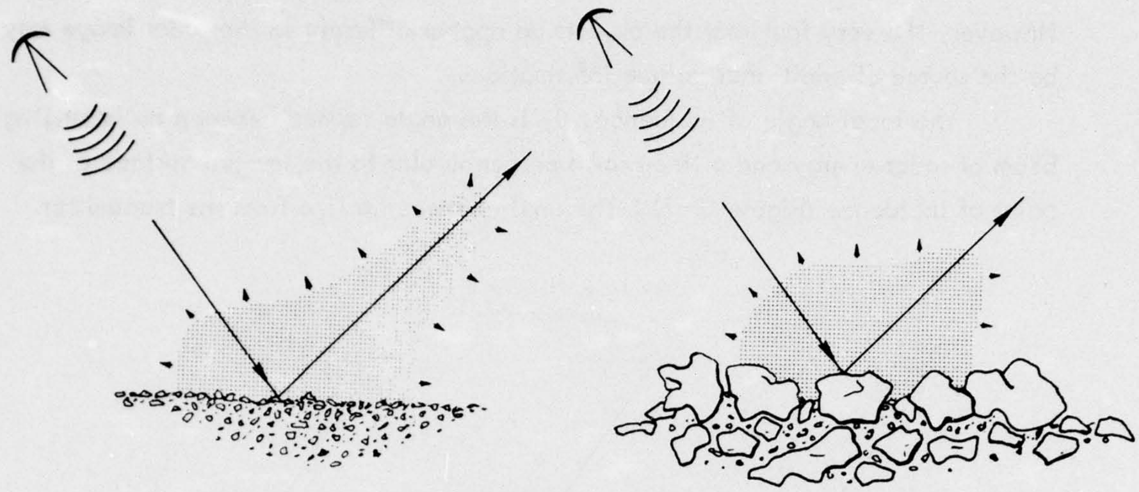

Figure G-8

Reflection of incident energy. Stippled pattern indicates relative intensities away from point of impact of ray.

surface, strong backscatter is recorded only near vertical incidence, achieved in the near range for relatively flat surfaces and in the far range for properly oriented steep-sloped terrain.

If surface irregularities are a significant fraction of a wavelength, more energy will be scattered at angles other than near specular (Figure G-8). Although any given moderately rough (relative to wavelength) horizontal surface will appear smoother at angles near grazing incidence, the intensity of radar return (backscatter) increases with decreasing incidence angle. However, for very rough (in terms of wavelength) surfaces, backscatter is nearly independent of incidence angle.

In interpretation, one must learn to "think radar", to realize that tonal contrasts are reflections of roughness and to a lesser extent dielectric contrasts rather than color contrasts as seen on the aerial photo.

Shadows

The shadowing effects of primary scene objects aid the objects' identification in aerial photo interpretation. For example, it is much easier to identify storage tanks from their shadows than from their planimetric shapes alone.

Shadowing in the SLAR image is related not only to the primary scene objects but to regions of varying terrain slope within the image. In regions of high relative

relief, contiguous areas are obliterated by shadowing, therefore, data about contiguous areas cannot be provided. This can be overcome by careful mission planning which considers the relationship between relative relief and depression angles. MacDonald and Waite (1971)[22] provide an excellent basis for such planning in their Optimum Radar Depression Angles Map (Figures G-9a,b).

Valuable for generating imagery in continuous strip, with a wide swath format under nearly all weather conditions, radar is an outstanding reconnaissance and surveillance tool. The value of SLAR is further enhanced by the alternate use of high resolution - narrow swath imaging systems, which are particularly valuable for target identification, and coarse resolution systems which may be capable only of detection of small targets and other man-made elements. Programmable range increments for varying standoff distance and depression angle provide additional flexibility to the system. Its "sensing" in a non-visible portion of the electromagnetic spectrum often permits revelation of new data even in areas which have previously been subjected to intensive in estigation utilizing other airborne sensors. As earlier stated the format of SLAR is visual, the data are not (Figures 4a, 4b, pgs. 10-11).

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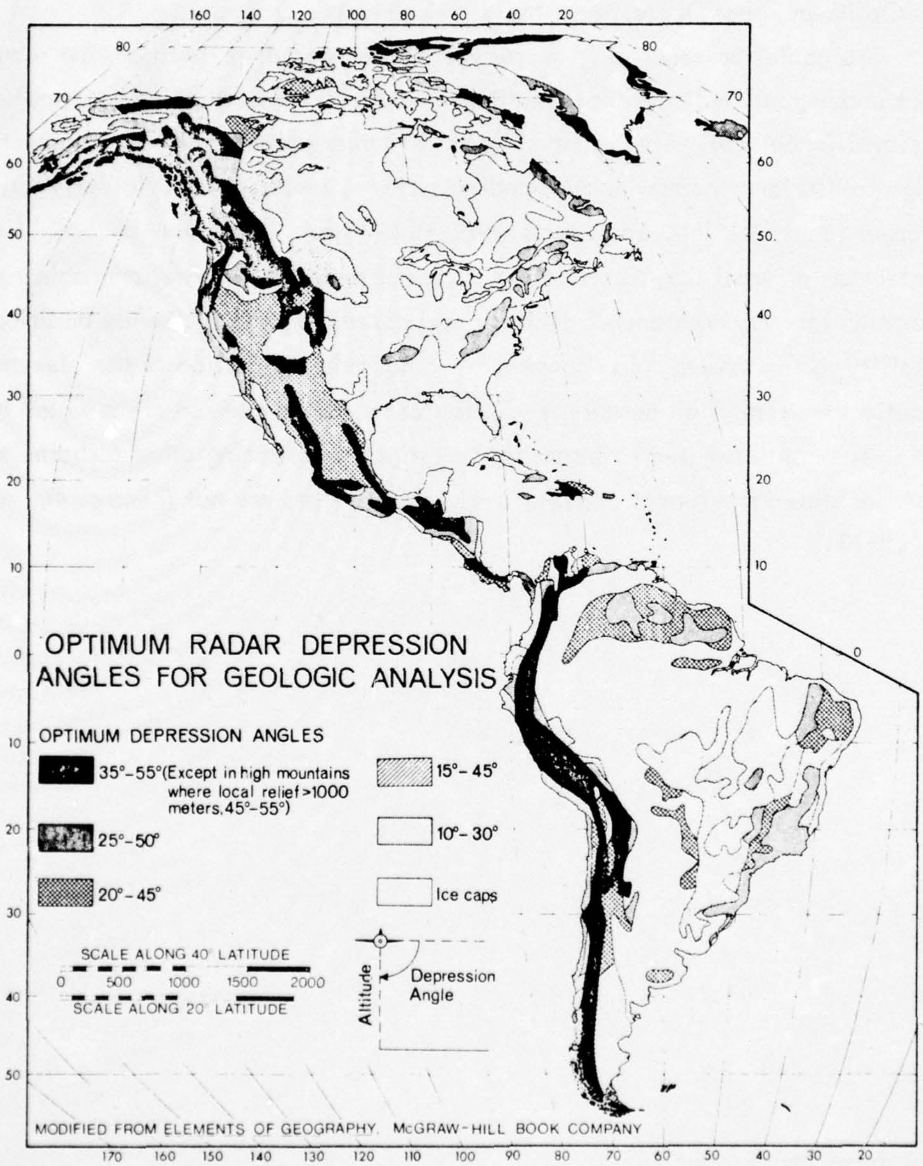
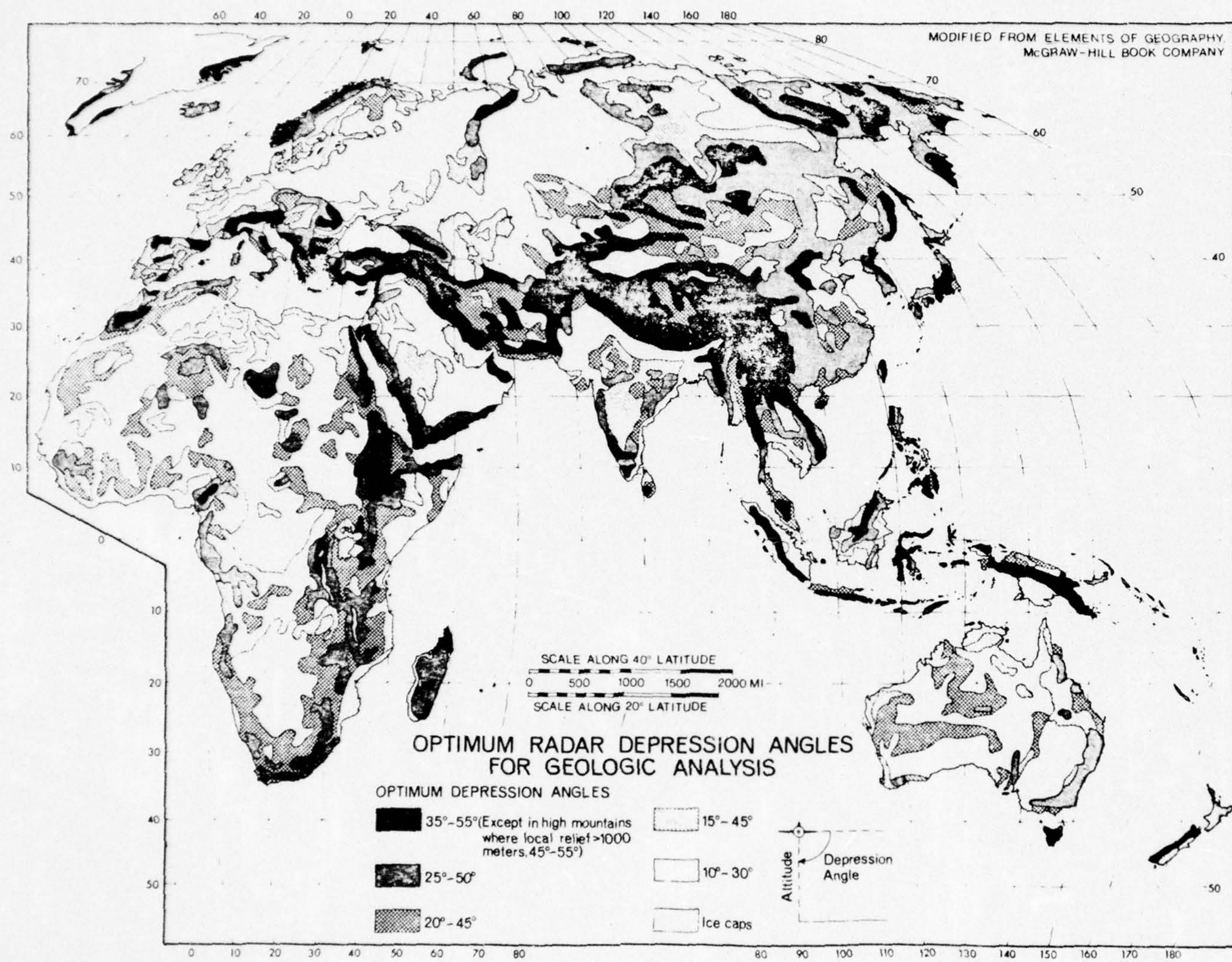
22 MacDonald, H.C. and W. P. Waite, "Optimum Radar Depression Angles for Geological Analysis," Modern Geology, vol. 2, pp. 170-193, 1971.



MacDonald and Waite, 1971

Figure G-9a



MacDonald and Waite, 1971

Figure G-9b

APPENDIX H
FREQUENCY EFFECTS IN RADAR

Numerous SLAR systems with a diversity of frequencies have been used as military and geoscience reconnaissance tools. Whether the result of the reconnaissance is the identification of man-made objects or a regional terrain analysis, the interpretation of the imagery is substantially controlled by the parameters of the radar system. Although the ground-controlled parameters (dielectric constant and surface configuration) may change during the period of image acquisition, as in the case of monitoring sea ice, etc., and these changes may facilitate special interpretations; most interpretations of available imagery consider static ground parameters with the manipulation of the system parameters. These system parameters include aircraft altitude, antenna depression angle, polarization, system frequency, resolution and gray scale averaging. All of these parameters influence the backscatter from an imaged surface, and manipulation of any one may afford the interpreter additional data.

The frequency range of imaging radars is from 220-390 MHz for P-band to 26.5-40 GHz for Ka-band radars. It is known that the lower frequency radars have a greater penetration capability than do the higher frequency radars, and also that the backscatter from a target depends upon the relation of the radar wavelength to the micro-relief or surface roughness of the target. Generally speaking, low frequency radars tend to smooth out micro-relief and therefore eliminate detail of the imaged feature's surface. Any surface will appear smooth to a radar if $h < \lambda/8 \sin \gamma$ (Beckman and Spizzichino, 1963)[23], where h is the vertical relief of surface irregularities, λ is the radar wavelength and γ is the grazing angle (or 90° - incident angle) of the radar wave path and the target surface.

Due to the varying degrees of penetration and the differences in energy/terrain interaction, one would expect that imagery produced by each radar band might contain data unique to that band. In the few instances where multifrequency imagery was available for the same area this was proven to be the case (Schaber, et. a., 1975;[24]

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23 Beckmann, P. and A. Spizzichino, The Scattering of Electromagnetic Waves from Rough Surfaces, MacMillan Press, New York, 128 p., 1963.

24 Schaber, G.G., G.L. Berlin and W.F. Brown, Jr., "Variations in Surface Roughness Within Death Valley, California: Geologic Evaluation of 25 cm Wavelength Radar Images," Geological Society of America Bulletin (in press), February, 1975, 35 pp.

Dellwig, 1969[25]).

Certainly a redundancy of data is inherent to multifrequency imaging. Features within an imaged area which can best be identified by shape, tone or texture are most easily recognized on fine resolution imagery. With real-aperture systems this means high frequencies must be used to achieve fine resolution. Avoiding redundancy is a matter of choosing the proper bands for a given purpose, and in most cases a single frequency is sufficient.

Cultural and Other Man-Made Features

Bryan (1975)[26] conducted an investigation to determine the nature of training needed to interpret radar imagery of an urban scene. X-band (8.0-12.5 GHz) and L-band (1.0-2.0 GHz), like and cross polarized imagery of the same scene was evaluated by 685 student interpreters. In many cases students expressed difficulty in identifying cultural features on the L-band imagery, although statistics showed only a "slight advantage for over-all interpretation using X-band imagery" (Bryan, 1975). A 20 minute discussion prior to a second interpretation session, tended to improve their ability to interpret the X-band imagery more than it did the L-band imagery. This suggests that more cultural data are extractable from high frequency imagery even by skilled interpreters.

Many cultural and man-made features within an imaged area give uniformly high returns, and interpretation of these features is based more on shape, size, pattern and proximity than on texture and tone. This is in part due to the high reflectivity of some man-made objects such as airplanes, bridges, railroad tracks and fences; and is also due to the unnaturally large number of dihedral and trihedral reflective surfaces found in man-made structures. For these reasons, high resolution radars are important, especially where shapes must be delineated for identification; but radar frequency is not as critical a consideration as for vegetation or geologic studies.

Regardless of frequency, urban areas and linear works of man are usually most advantageously imaged when aligned parallel to the flight line. This is due to the cardinal effect (Beatty, et. al., 1965)[27] and is best illustrated by the Maltese Cross

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[25] Dellwig, L.F., "An Evaluation of Multifrequency Radar Imagery of the Pisgah Crater Area, California," Modern Geology, vol. 1, pp. 65-73, 1969.

[26] Bryan, M.L., "Interpretation of an Urban Scene Using Multi-Channel Radar Imagery," in: Remote Sensing of Environment, (in press), May, 1975, 25 pp.

[27] Beatty, F.D., et. al., "Geoscience Potentials of Side-Looking Radar," Raytheon/Autometric Corp., 90 p., 1965.

developed in Sun City, Arizona. This is the result of high return from structures aligned normal and parallel to look direction in a residential area in which structures are oriented tangent to circular roadways (Figure H-1).

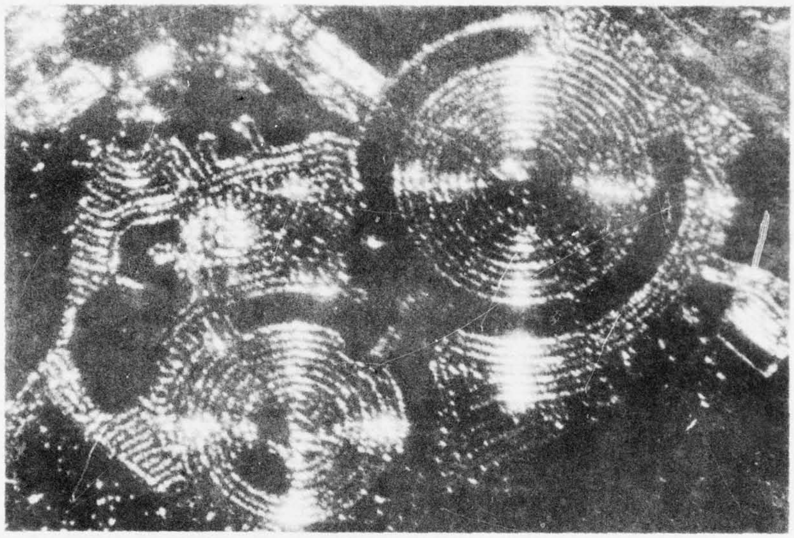

Figure H-1. Sun City, Arizona, Strategic Air Command Imagery.

In areas where hard targets, such as vehicles, buildings or aircraft, may be concealed under vegetation canopy, obviously a radar of lower frequency than K and possibly X-band must be utilized for detection. The proper choice of frequencies to allow shape and size delineation and also penetration of certain vegetation merit investigation.

Geologic Elements

Some significant results have been obtained from multifrequency imagery of geologic features, especially in arid regions where vegetation does not preclude the use of high frequency systems. Dellwig (1969)[28] observed that an alluvial fan, whose surface was composed of sub-angular rock fragments of which 75 percent were smaller than 2.5 cm, was easily delineated on K-band imagery, since the surface appeared rough to the radar and the backscatter was largely diffuse in contrast to the adjacent smooth playa lake surface (no return), however, the same fan could not be distinguished on the P-band imagery.

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[28] Dellwig (1969). op. cit.

AD-A033 557 KANSAS UNIV/CENTER FOR RESEARCH INC LAWRENCE REMOTE --ETC F/G 17/9
A DEMONSTRATION AND EVALUATION OF THE UTILIZATION OF SIDE LOOKI--ETC(U)
OCT 76 L F DELLWIG, B C HANSON, N E HARDY DAAG02-75-C-0145

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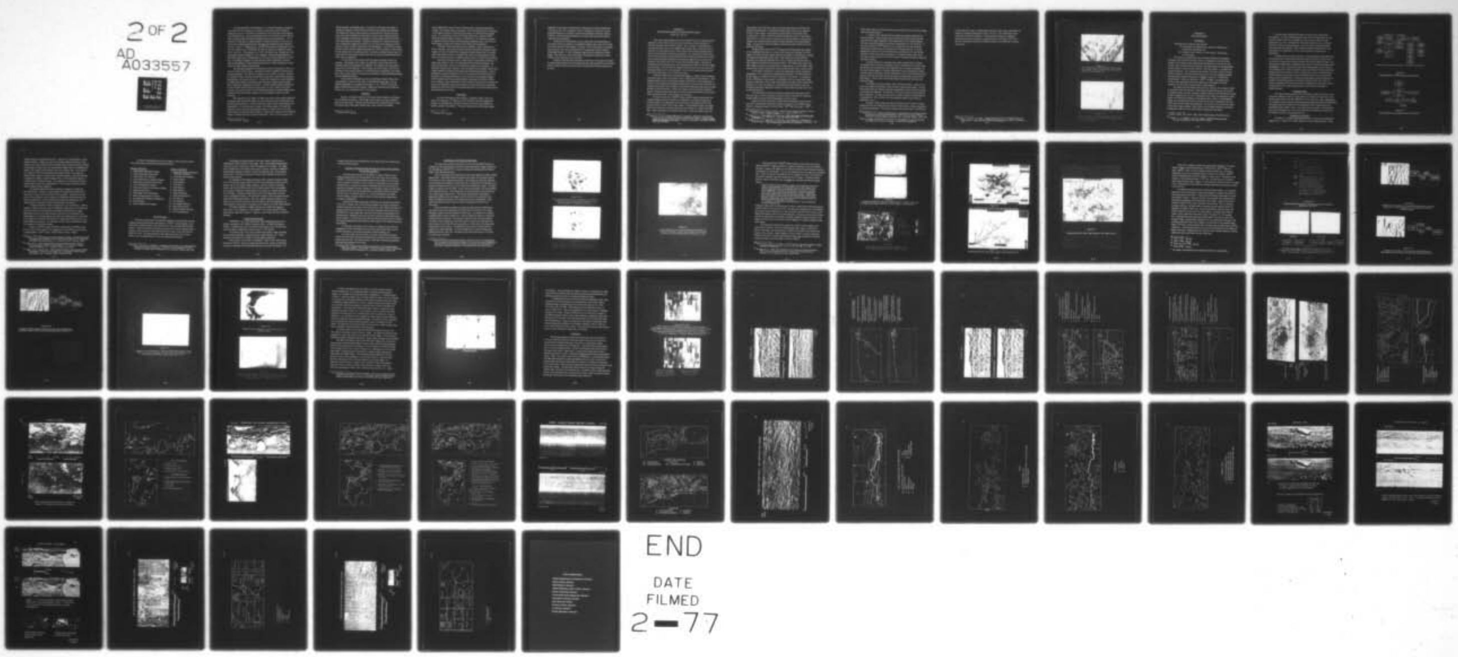

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For many geomorphic interpretations K- or X-band radar systems are superior, since details of surface roughness and moisture content help to delimit landform categories; but even at the expense of redundancy certain data may only be gleaned from additional bands. Rock size distribution over areas of alluvium may be inferred fairly accurately using the Rayleigh breakpoint at given radar frequencies. This is the point at which there is a sharp reduction in diffuse return power, due to the size of the surface elements producing the return decreasing beyond the radar detectable size of $h < \lambda/8 \sin\gamma$. Schaber et. al., (1975)[29] discovered that this breakpoint occurs for L-band radar (1.0-2.0 GHz) when the radius of curvature of pebbles is between 0.08λ and 0.14λ. This represents a 4.0 to 7.0 cm pebble size. Samples taken from the breakpoint region averaged 4.1 cm in diameter, and the predicted diameter at a 52^o grazing angle was $h < 25cm/8\sin52^o$ or 3.96 cm, the theory correlating well with fact. Knowledge of fragment size finds important military application in tactical mobility determinations, field fortification construction, barrier planning and aircraft (especially light) landing site designation.

The preceding paragraphs have discussed the effects of frequency on the use of radar for tactical terrain analysis. Elsewhere the needs for different resolutions have also been addressed. The discussion of frequency and resolution, however, would not be complete without a discussion of resolution in gray-scale, and the broad frequency bands that may be needed to achieve it. A trade-off is possible for a given bandwidth and SAR antenna physical size between spatial resolution and gray-scale resolution that is improved by averaging incoherently. If all the available signal bandwidth and all the available synthetic-aperture signal history are used to achieve fine spatial resolution, the typical "speckle" of the SAR image (caused by multipath fading) results in reduced utility of the image compared with a photographic image of the same resolution.

The trade-off is not as simple as it might seem since the eye performs significant averaging so that for relatively large scales many interpreters seem to think that finer and finer spatial resolution is all that is required to achieve better interpretability and detectability. On the other hand, as shown in the adjunct report, the resolutions required to achieve the same interpretability differ by a factor of from 2 to 4 when coherent (finest resolution possible) imagery is compared with images for which sufficient numbers of samples have been averaged incoherently. That is, one can get by with a

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29 Schaber (1975). op. cit.

spatial resolution considerably poorer, if each cell in the image is the result of incoherent averaging, and the gray-scale resolution has therefore been improved. This improvement in gray-scale resolution can be achieved in either of two ways: using more range bandwidth than required for the final range resolution (panchromatic averaging) or incoherently processing to achieve poorer resolution with SAR than would otherwise be possible. Significant improvement is achieved with use of only 4 independent samples per resolution cell, but 10 or more samples per cell are needed to achieve dramatic improvement in interpretability. If we make the assumption that the best azimuth resolution attainable by an SAR is required, we must assume that the panchromatic averaging technique is necessary to improve the gray scale. In many tactical terrain analysis situations this seems to call for transmission bandwidths of the order of a gigaHertz.

It is also shown in the adjunct report that square resolution cells are not necessary. Rectangular cells in which one dimension is small and the other considerably larger give interpretability comparable with something like the geometric mean of the two cell dimensions. This technique can also be used to aid in the improvement in gray-scale resolution, for if spatial resolution capability in one dimension is greater than required, the other may be degraded, thereby permitting averaging of more independent samples.

Seven distinct backscattering units were delineated in Death Valley using L-band imagery, and one of these units, the Rayleigh breakpoint zone, was not specifically mapable as a geologic unit (Schaber, et. al., 1975)[30]. X-band did appear to differentiate between chloride, sulphate and carbonate facies within the salt pan units, but verification of this is not complete.

Vegetation

Because of its higher sensitivity to fine-scale surface roughness, and because of no significant penetration, K-band radar is better suited for certain vegetation studies than other bands. Although identification of plant communities per se cannot be achieved using K-band radar imagery alone, plant community boundaries

[30] Schaber (1975). op. cit.

may be delineated by tonal or textural contrasts; and by shadowing produced by changes in the canopy height; consequently, with a knowledge of plant communities in the target environment, inferences may be made as to the identification of the plants. In a multifrequency study of the Pisgah Crater Area, Dellwig (1969)[31] found that although imagery in bands K, (4.46 GHz) and P indicated the presence of vegetation by tonal contrast with surrounding unvegetated areas, only on the K-band imagery was there any indication of the density of the vegetation.

Although K-band seems best suited for vegetation studies, particularly in arid environments, some success has been achieved using synthetic aperture X-band imagery, but since the reflectivity of vegetation depends largely upon leaf configuration and moisture content it is doubtful that radars of lower frequency would be useful for collecting the type of vegetation data required in military terrain analysis.

Agricultural elements require a combination of interpretation parameters. To simply state whether or not it is an agricultural feature requires only shape, size, pattern and proximity, which may be provided by imagery at any frequency. A qualitative interpretation, however, would most likely only be possible using K-band imagery assisted by computer enhancement and discrimination techniques. Such an interpretation might be significant in a military situation from the point of view of the degree of concealment offered by various crops and at varying growth stages. Tactical considerations of concealment might be concerned with whether a field is corn or cabbage. Much information of value to selection of frequency or multiple frequencies for vegetation study has been obtained by recent multi-octave backscatter measurements from field crops but these observations have not yet been evaluated with image interpretation as a goal.

Conclusions

Too little multifrequency SLAR imagery is available to make a fair evaluation of its usefulness. The imagery which is available, however, suggests that imaging in two frequencies, particularly K-band and P-band, may be useful for regional geologic interpretations. The higher frequencies most effectively enable

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31 Dellwig (1969), op. cit.

separation of rock types, the combination of frequencies facilitates classification of surfaces on the basis of roughness, and lower frequencies may permit (in some cases) identification of sub-alluvial contacts and estimation of minimum alluvium thickness. Using the Rayleigh breakpoints of various bands may also be useful to mapping alluvial boundaries.

Delineation and classification of plant communities and identification of most cultural features at present is accomplished somewhat more easily with K-band or synthetic aperture X-band imagery. However, with an improvement in resolution, lower frequency radars may use penetration to an advantage to locate hidden or camouflaged features. As with the geologic applications of multifrequency SLAR imagery, this would be a matter of selecting the appropriate frequencies or bandwidths such that redundancy was worthwhile.

Analysis of data like those collected for field crops will be especially helpful in answering these questions; but the experiments need to be extended to a much wider variety of targets relevant to tactical terrain analysis before strong conclusions can be drawn.

APPENDIX J
POLARIZATION EFFECTS IN RADAR RETURN SIGNAL
(Plates VII, VIII, IX)

Some radar imaging systems such as the AN/APQ-97 have a multipolarization capability by which they are able to transmit and receive either horizontally or vertically polarized electromagnetic energy. Thus, if energy is transmitted from a vertically polarized antenna, the radiated radar energy is also vertically polarized. However, the return signal may have both vertical and horizontal components due to terrain factors affecting the reflected polarization. By receiving the returning echo with vertically polarized and horizontally polarized antennas, both the like (vertical) and the cross (horizontal) components of the returning signal can be recorded simultaneously in the form of like (VV) and cross (VH) polarized images. Likewise, by transmitting in the horizontal mode, the corresponding like (HH) and cross (HV) images can be recorded. The like and cross images of either polarization are not only simultaneously produced, but are also congruent. Thus, the two images represent records taken at the same instant in time over the same area.

Since the introduction of multipolarized imagery, a number of terrain elements have been noted to have a return signal which is highly polarization dependent. These elements produce like and cross polarized images which differ in tone and thus give a reversal in tonal contrast with adjacent targets which have similar tones on the like and cross polarized images. Three examples of polarization dependent radar returns are those produced by cultural features, certain rock outcrops, and areas of high soil moisture content. Multi-polarized return signals have been studied and found to contain unique target information related to these three terrain elements.

A study by Lewis et al. (1969)[32] of linear cultural features revealed that like-polarized imagery proved to be better for the detection of railroads and powerlines oriented parallel to the flight path and the detection of transportation arteries that traverse no-return terrain, such as water bodies. Cross-polarized imagery was judged better for the detection of railroads and power lines oriented at an angle to the flight path. These conclusions are illustrated in Plate VII. Urban and industrial areas are

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32 Lewis, A. J., H. C. MacDonald and D. S. Simonett, "Detection of High Return Linear Cultural Features on Multiple Polarized Radar Imagery," Proc. 6th Symp. on Remote Sensing of Environment, University of Michigan, Ann Arbor, October, 1969, pp. 879-894.

more apparent on the HH (like) image as are those communication lines which are parallel to the flight path. Non-parallel communication lines are more apparent on the HV (cross) image. Tests involving a large number of interpreters verify this observation. Similar orientation-related contrasts can be seen in the Freeport area (Plate I), in which vessels on canals are more clearly defined on like polarized imagery, and communications networks are better displayed on the cross polarized image. It is also to be noted that offshore conditions are better defined on the like polarized (HH) image.

MacDonald and Waite (1971),[33] working with multipolarized radar imagery of the Atchafalaya River basin in Louisiana found strong tonal contrasts in the near range of HH (like) polarized imagery which did not appear on simultaneously recorded HV (cross) polarized imagery (Plate VIII). Field examination revealed that the vegetation was completely defoliated at the time of imaging and discrimination of major vegetation boundaries was extremely difficult. The lighter toned areas on the radar imagery were found to represent the true swamp regions, while the darker toned patterns were indicative of the better drained, relatively drier soils of natural levees.

On the basis of field data, as well as the examination of aerial and ground photography, it was concluded that differences between light- and dark-toned areas on the imagery are related to the relative amounts of soil moisture. It also appears that these differences in soil moisture are detectable in the near range of the image through a canopy that in the far range would dominate the reflection from these areas. Basically it is a matter of looking (at a large depression angle) between trees and through bare branches as opposed to looking (at a small depression angle) into a maze of trunks and branches.

Two characteristics of these soil moisture related tonal differences are that they only occur on the like-polarized image and that they decrease with increasing incident angle; the contrast thus being greatest in the near range.

Recent work at the University of Kansas Center for Research using the Microwave Active Spectrometer (MAS) has validated the conclusions of MacDonald and Waite for a frequency range of 4-8 GHz (Ulaby, 1975[34] and Ulaby et al., 1975)[35].

[33] MacDonald, H. C. and W. P. Waite, "Optimum Radar Depression Angles for Geological Analysis," Modern Geology, vol. 2 , pp. 170-193, 1971.

[34] Ulaby, F. T., "Radar Response to Vegetation," IEEE Transactions on Antennas and Propagation, vol. AP-22, no. 2, pp. 257-265, March 1975.

[35] Ulaby, F. T., T. F. Bush and P. P. Batlivala, "Radar Response to Vegetation II: 8-18 GHz Band," IEEE Transactions on Antennas and Propagation, September, 1975.

These results indicate a similar high response to soil moisture at low incidence angles and with HH polarization*.

A number of rock outcrops have been observed to produce anomalous depolarized returns. These outcrops always produce bright like-polarized and dark cross polarized images independent of the polarization of the transmitted signal. The lower cross-polarized returns also appear independently of look-direction. A study by McCauley (1973)[36] found that, for the most part, the rocks producing anomalous cross-polarized can be grouped into three general types: (1) certain geologically recent lava flows (late Pleistocene and Holocene), (2) some Tertiary volcanics and (3) certain massive sandstones. For differing reasons, these three rock types, produce terrains in which radar return is dominated by specular reflection from planar surfaces.

Outcrops of the three rock types share certain characteristics: (1) planar rock surfaces that are large in comparison with the wavelength of the incident radar are abundant and detrital material and vegetation are of secondary importance; (2) the planar surfaces appear to contribute significantly to the returning radar energy, with this energy maintaining a constant polarization; and (3) the outcrop areas are of sufficient size and sufficiently uniform character to be delineated on small scale K-band imagery. Hence, these rocks produce bright like-polarized and dark cross-polarized images.

An example of such an outcrop is shown in Plate IX overlay. Lavas A, E, F, and G have bright like-polarized images and dark cross-polarized images. The surfaces of these flows are littered with large faceted blocks of lava that act as specular non-depolarizing reflectors. The flows B, C and D are covered by volcanic ash and sparse vegetation. This type of surface acts as a diffuse reflector with good depolarizing properties. Thus, the like- and cross-polarized images of these flows are comparable in tone.

Contrasts in differentially polarized return signals can be utilized in visual comparison of the two images for the revelation of soil moisture, surface configuration or orientation phenomena. More subtle contrasts, which may escape visual detection

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[36] McCauley, J. R., "Surface Configuration as an Explanation for Lithology-Related Cross-Polarized Radar Image Anomalies," CRES Technical Report 177-36, University of Kansas Center for Research, Inc., Lawrence, Kansas, April 1973.

*Note: At angles within 20-31° of vertical, VV and HHare so nearly the same that any difference is likely to be system, not polarization dependent.

in black and white images, might be better detected through a color combination of images with orthogonal polarization (Figures J-1a,b). Such combination of tone and texture of each scene element in both polarization images may enable the separation of elements not otherwise separable (Coiner and Morain, 1971)[37] and thus are invaluable and should be considered essential in the collection of tactical terrain data.

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[37] Coiner, J. C. and S. A. Morain, "Image Interpretation Keys to Support Analysis of SLAR Imagery," Proc. 1971 ASP-ACSM Fall Convention, pp. 393-412, September 1971.

Figure J-1a
Color combination of HH (blue) and HV (red) imagery near Freeport, Texas. Marshy areas which produce higher HV returns appear red.

Figure J-1b
Color combination of HH (green) and HV (yellow) imagery near Freeport, Texas. Marshy areas which produce higher HV returns appear yellow.

APPENDIX K
DATA PROCESSING

Introduction

Processing has two different kinds of goals:

(1) Enhancement and combination to improve the efficiency of human image interpreters; and

(2) Automatic data extraction to improve speed, completeness, and consistency.

This section will describe the data processing techniques and equipment developed at the University of Kansas, that are of importance in tactical terrain analysis of radar imagery; these efforts being representative of work done at other centers.* Since the main thrust of this report is the demonstration of the applicability of radar imagery in tactical terrain analysis, either radar imagery or surrogate data has been focused on. In an actual tactical situation, data from a variety of sources would be employed. This would further enhance the value of automated processing techniques but is properly the subject of a different study (e.g., "MITHRA Processing System", Currier and Holtzman, 1975).[38] Therefore, the emphasis here will be on those techniques which have supported or could support the studies reported in the main part of this document or similar analyses.

The image processing efforts at The University of Kansas were initiated in 1964 in conjunction with radar research. Both analog and digital techniques were pursued in parallel initially, and later combined to optimize the amount of information extracted by photo interpreters per unit time. Although the work started with processing of radar images, the similarity of techniques for processing radar, scanner, and photographic images was recognized from the start, and some of the earliest experiments were with combinations of radar images and photographs. The paucity in the data base at Kansas of good radar images produced in later years, led to a greater emphasis on processing multispectral image sets in the visible and near infrared spectral ranges.

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* USAETL, RADC, GE, NASA, ERIM, Purdue (digital only), JPL (digital only).

38 Currier, P., J. Holtzman, and V.H. Kaupp, "MITHRA Processing System" (in press) Final Report, ETL DAAK 02-73-C-0106.

For most image processing techniques, the source of the images used is not important. The same techniques apply to any kind of multiple-image set, and techniques used to enhance a photograph may also be used to enhance a radar image--and vice versa. Although both of the goals listed above can be achieved with either digital or analog processing, at The University of Kansas the analog techniques have been applied to both, whereas the digital techniques have been used primarily for classification. Work is well underway to combine these capabilities.

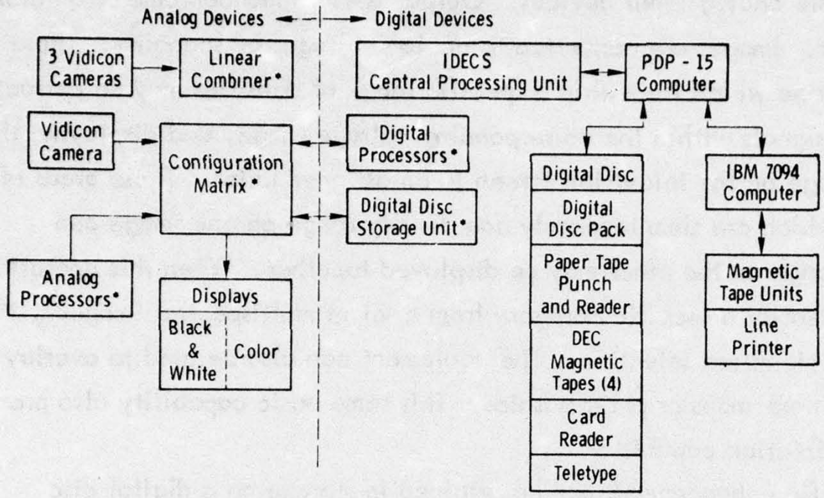
A major problem in image processing is communicating the results effectively to the human user. Neither black-and-white images nor tables of numbers utilize the eye-brain communication channel as effectively as color images and maps. This has long been recognized by cartographers (one rarely sees single-color maps) and by photographers. Thus, a major initial goal of the Kansas program was to develop a color display system to allow simultaneous color presentation of multiple monochrome images, some of which might be in their original form, and some in enhanced form. This philosophy has continued to guide the development of the various systems for enhancement and classification. Another, perhaps stronger motivation has been the concept of interaction between the interpreter and the machine aids. Thus, the computer language and/or analog controls are completely photo interpreter oriented. The description of the image processing systems which follows accordingly is similarly phrased.

Processing Systems

The image processing systems at The University of Kansas consist of two interfaced main subsystems (Figure K-1) and a third to be merged in the near future. The digital systems consists of an IBM 7094/PDP-15 set of computers, using a sophisticated set of image-processing software called Kansas Digital Image Data System (KANDIDATS). The digital systems are interfaced to the Image Discrimination, Enhancement and Combination System (IDECS) which is an analog electronic system. The third system is an optical processing unit. Most of the experiments described later were done on the IDECS; this system is described briefly first.

Description of the IDECS

The IDECS is a multiple image processing hybrid, containing an analog and a digital section. Figure K-2 is a block diagram of the main system elements. Three



* Indicates some function may be computer controlled through the IDECS Central Processing Unit.

Figure K-1

Major subsystem of IDECS image processing systems.

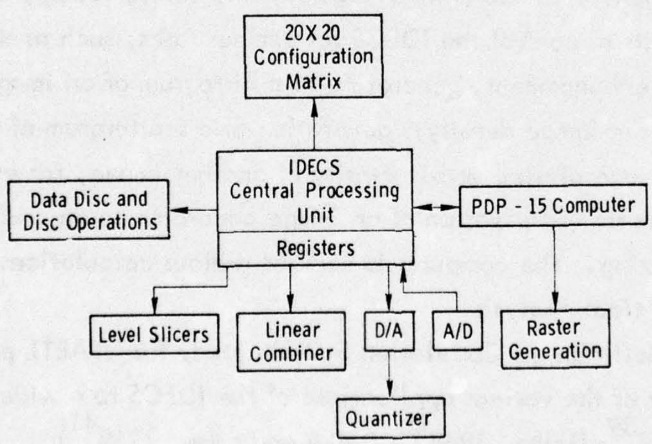


Figure K-2

Block diagram of main system elements of the IDECS.

vidicon cameras are analog input devices. Output is via a monochrome or a color television monitor. Images are converted to analog voltages by scanning. Those portions of the image which lie within a specific range of densities may be extracted by detecting the signals within the corresponding voltage range, and displaying this portion of the image on the television screen in an assigned color. Those areas of the 3-image set which are simultaneously one density range on one image and another density range on the other may be displayed together. When this operation is performed to identify a specific category from a set of multispectral imagery, it is called spectral signature selection. The equipment can also be used to overlay enhancements on base-maps or photomosaics. This same basic capability also provides a change detection capability.

Any specific enhancement may be retained in storage on a digital disc for later viewing. Similarly, an entire image can be digitized and stored; this is done when an image is to be manipulated in the computer. Hard-wired circuitry exists for direct density-to-hue conversion, for delineating specific portions of an image for enhancement, and for automatic level selection corresponding to the densities found in some portion of the image defined by the operator.

For digital capability, IDECS is interfaced to, and controlled by, a PDP 15 computer. Software exists to control the IDECS for various tasks, such as determination of the total area of enhancement, generation of a histogram of an image (distribution function of the image density), generation of a scattergram of two images (density of one image plotted versus density of another image, for each point in the image); and automatic quantization of an image according to any rule, e.g., equal probability quantizing. The computer is best for tedious calculations, repetitive operations and statistical analysis.

Reports on the Multi-Image Correlation Systems Study for USAETL provide the best overall summary of the various applications of the IDECS to a wide variety of problems (Dalke, 1967[39]; Dalke, 1968[40]; Dalke and Estes, 1968[41]).

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39 Dalke, G.W., "Identification of Remote Objects by Means of Scatterometry Data and Application to Pisgah Crater," CRES Technical Report 61-17, University of Kansas Center for Research, Inc., Lawrence, Kansas, February 1967.

40 Dalke, G.W., "Multi-Image Correlation Systems Study for MGI, Phase II Technical Report," CRES Technical Report 122-3, University of Kansas Center for Research, Inc., Lawrence, Kansas, June 1968.

41 Dalke, G.W. and J.E. Estes, "Multi-Image Correlation Systems Study for MGI, Final Report," CRES Technical Report 122-4, University of Kansas Center for Research, Inc., Lawrence, Kansas, December 1968.

A listing of the subheadings in the two chapters, 4 and 5, gives an indication of the variety of operations and subsystems possible:

Chapter 4 (TR 122-4)

1. Single Image Monochrome Display
2. Single Image Edge Enhancement
3. Single Image Level Selection
4. Area Measurement for Isodensity Regions
5. Single Image Probability Distributions
6. Line Scan Modulation Displays
7. Single Line Selection Densitometry Displays
8. Image Framing Device
9. Multi-Image Color Combinations
10. Multiple Image Signature Selection
11. Two-Image Joint Probability Distribution
12. Flicker Display
13. Optical Combination of Imagery

Chapter 5 (TR 122-4)

1. Image Scan Format and Implicit Parameter Dependence
2. Synchronization Generator
3. Image Scanners
4. Image Displays
5. Color Matrix
6. Level Selector
7. Edge Enhancer
8. Signature Selector
9. Image Framing Device
10. Line Selector
11. Area Integrator
12. Pulse Height Analyzer
13. Image Flicker Device
14. Optical Additive Combiner
15. Line Scan Modulator

Optical Processor

Recently, an optical system for producing images from radar holograms has been added and used at Kansas (Dickey and Holtzman, 1972).[42] A radar hologram is produced from a synthetic-aperture radar signal film; or it may be produced from digital signals. It contains the same information as the signal film, but all ranges have been brought to the same focus so that reconstruction of the image is easier than from the signal film itself. The image produced in the hologram processor may be viewed directly, may be recorded on film, or may be measured electronically.

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42 Dickey, F.M. and J.C. Holtzman, "Comparison of Quadrature and Non-Quadrature Imaging Radar System Performance," CRES Technical Memorandum 177-29, University of Kansas Center for Research, Inc., Lawrence, Kansas, June 1972.

The hologram processor produces at one point along its optical bench a 2-dimensional Fourier transform of the image. Thus, various optical filtering techniques can be used at this point to modify the properties of the image. The images used in another part of this study having varying resolutions, amounts of incoherent and coherent averaging, and aspect ratios for the resolution cells, were produced on this system. Of course, other kinds of Fourier-plane filtering can also be performed in the processor.

An advantage of the hologram processor is that it permits viewing the image with its full dynamic range, without the dynamic range degradation enforced by the limited range of film used for image recording. Since the electronic measuring devices used with the IDECS do not have the limited range of film, measurements can be made of intensities in different parts of the image that would be impossible on a film image. Placing an image dissector tube in the image plane of the processor, planned for the future, will permit direct transfer of the wide-dynamic-range signal to the IDECS for processing. Of course, digitally processed images do not require this step, for they may have whatever dynamic range the digitization word length permits; and they may be introduced into the IDECS via the PDP 15/20 computer.

The optical capability is capable of being made sufficiently rugged for tactical use. This is important, as the hologram is an excellent method of storing large dynamic range data in general. Moreover, normal image data can be optically processed.

Digital Image Processing

KANDIDATS is much like other general image processing systems such as VICAN, developed at JPL, IDIMS, developed at ESL, and DIMES developed at USAETL. Investigators who know little about programming can use this interactive system by typing an appropriate command string on a CRT terminal.

The operations part of the system includes image editing, image combining, general image manipulation, image quantizing, image holograms, etc. Pattern recognition operations are available as are fast transform operations.

When reviewed in its entirety, KANDIDATS, IDECS and the optical processor provide a flexible, interactive image processing system, capable of performing the gamut of operations from bookkeeping through enhancement and display. The

examples which follow are representative of the results which are of significance in tactical terrain analysis.

Examples of Automated Image Processing for Tactical Terrain Analysis

Formula Map Generation

An interesting application of the IDECS as a rapid, automatic terrain analysis mapping device was demonstrated in the "factor map" project (Currier, 1972).[43] An empirical formula (model) to determine the length of time it would take to construct an airfield in a given location, used manually in current USAF and USA practice, requires six pieces of information related to tactical terrain analysis (soil strength, moisture, vegetation, soil thickness, slope, and soil type); the type of airfield to be constructed (liaison, surveillance, light lift, medium lift, heavy lift, or tactical); and who is to do the construction (air mobile division engineer, engineer combat, airborne division engineer supplemented, or engineer construction).

To perform the task, the geographic information was presented to the IDECS in the form of category maps which were grey-coded, so the category subdivisions could be entered via the vidicon and the level slicers. After entering the data, the computer would query the operator as to the other variables and then write out on the IDECS disc a color-coded map, where the color contours corresponded to construction times. Although in the case in point all of the factor maps had been previously created, it was felt that much of the required data could have been extracted from aerial photography and high resolution radar imagery via the analytical portions of the IDECS.

In 10 minutes the overlays can be read on, recombined by the model and remapped for the area of 28 square miles in terms of some tactical factor such as airfield construction, cross country movement, tactical bridging, etc.

In an operational tactical situation, the factor maps could be produced directly from the imagery and almost instantaneously the model can be evaluated to produce the final map. This should be kept in mind when reviewing the demonstrations described elsewhere in this report.

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[43] Currier, Phil, "Terrain Factor Analysis and Automatic Color Coded Mapping Utilizing the IDECS," Final Report, CRES Technical Report 208-1, University of Kansas Center for Research, Inc., Lawrence, Kansas, August 1972.

Applications of the IDECS to Radar Images

The radar data available during most of the time that the IDECS has been in existence are the single-frequency (35 GHz) multiple polarization images produced by the Westinghouse AN/APQ-97. A majority of these were obtained during flights for NASA in the 1965-66 time frame.

One of the earliest color combinations tried was an image of the NASA Johnson Space Center. Horizontal transmit-horizontal receive (HH) and horizontal transmit-vertical receive (HV) images were combined. The buildings are relatively rough and give relatively strong responses on both HH and HV, whereas cars in the parking lot are smoother and depolarize less, so the HV image of the parking lots is weak. The result is shown in Figures K-3a and K-3b*, which contain two examples of the many different color combinations tried. The buildings are in red and blue-white, and the parking lots in green and red respectively. The tactical implications are that features appearing as differences on one image but not the other can be immediately combined and enhanced, speeding up the interpretation process immeasurably. Also, when one example has been found, the system extrapolates this rapidly to the entire area.

Color combinations using both the optical and the electronic methods were also made for some of the areas along the Gulf Coast with the HH and HV images, although no ground truth was collected for these areas. An example of an optically combined image is shown in Figure K-4. Note the fields that stand out in dark blue and dark blue with turquoise. The turquoise is believed to be a partially flooded rice field, with the stronger HH return coming from the plants protruding above the water surface, but with the HV return suppressed as it often seems to be where plants project above a water surface. The dark blue is believed to be a field where the vegetation is totally submerged. The spoil dredged from one ditch has blue water puddled behind each spoil pile. An analysis such as this would have tactical value for cross-country movement.

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* In these and other color pictures that follow, some of the colors in the description may not appear on the reproduced images. This occurs because the descriptions are based on the first-generation slides, whereas color prints prepared for the report (and "duplicate" slides) do not always duplicate the original colors.

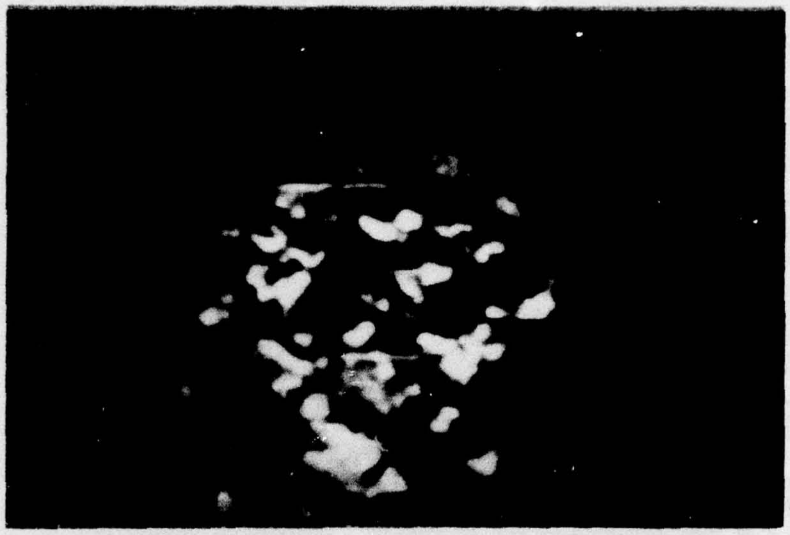

Figure K-3a

Color combination of like- and cross-polarized AN/APQ-97 images of Johnson Space Center near Houston, Texas. Buildings appear red and parking lots green.

Figure K-3b

Color combination of like- and cross-polarized AN/APQ-97 images of Johnson Space Center near Houston, Texas. Buildings appear blue-white and parking lots appear red.

Figure K-4

Color combination of like- and cross-polarized AN/APQ-97 images of area along the Gulf coast of Texas. Linear feature extending through the image almost horizontally is a canal.

Morain and Simonett (1967)[44] made an extensive study of the use of multi-polarized APQ-97 imagery and IDECS in vegetation mapping in the area of Horsefly Mountain, Oregon; such mapping is of tactical importance for determining the potential of vegetation for concealment. Some of the illustrations from their paper are reproduced here. Figure K-5 shows the original HH and HV images of the area, with Figure K-6 showing the vegetation map that corresponds with the images. An edited quotation from their paper is used below only to annotate the accompanying IDECS-processed images:

> Figure K-7 shows a color-combined image with a forest-type map overlay which has been adjusted to fit the geometry of the radar image. The central medium gray area (which appears violet on the color combination) is sagebrush. The areas above and below with paler tones (green on the color image) consist of ponderosa pine. Within the sagebrush area little pockets of pine forest are also discriminable. Areas of dark gray to the south of Otto Boy Flat and on the upper slopes of Horsefly Mountain, (darker green on color combination) correlate partially with areas of white fir forest rather than pine...
> ...A number of very dark gray areas (deep blue on color combination) are mesic grassland sites.

Clipping to display only the brightest parts of the HV image discriminates dense sapling and pole timber in the pine forest (K-8). Decreasing the clipping level to intermediate level of gray scale (not shown) and to the lowest gray scale level (K-9) results in additional discrimination within certain restricted areas. Furthermore, Morain and Simonett utilized the capabilities of the IDECS to establish probability density functions for the images to test the utility of this kind of textural approach to identifying different vegetation regions.

The results show potentials for applications to both tactical vegetation and tactical terrain analysis. The use of multipolarized radar imagery permitted production of the maps, and the application of IDECS both speeded up and improved the accuracy of the process. Further capability of such a system to provide unique data through a combination of sliced edge-enhanced images with unmodified or enhanced background images was demonstrated by Knuckey (1966).[45]

---

[44] Morain, S.A. and D. S. Simonett, "K-Band Radar in Vegetation Mapping," Photogrammetric Engineering, vol. 33, no. 7, pp. 730-740, July 1967.

[45] Knuckey, R. L., "Multi-Color Presentation of Images with Edge Enhancement," CRES Technical Memorandum 61-42, University of Kansas Center for Research, Inc., Lawrence, Kansas, October 1966.

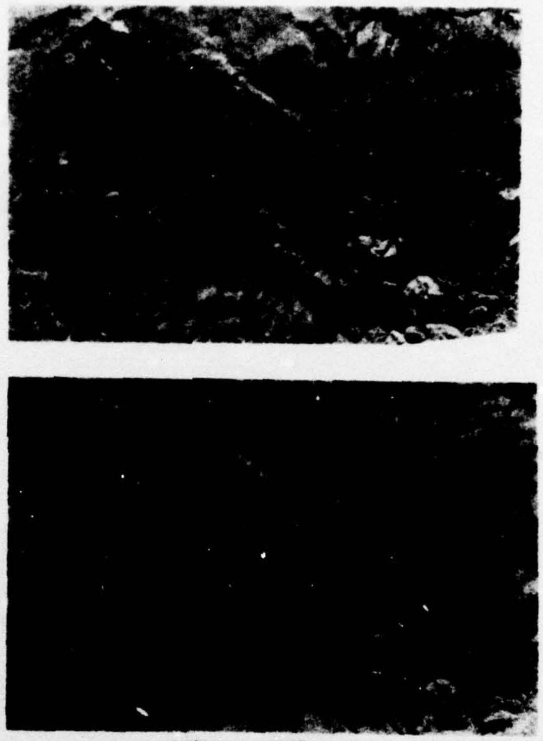

Figure K-5

Original AN/APQ-97 images of Horsefly Mountain, Oregon, study area. Top image is horizontally polarized. Bottom image is cross-polarized.

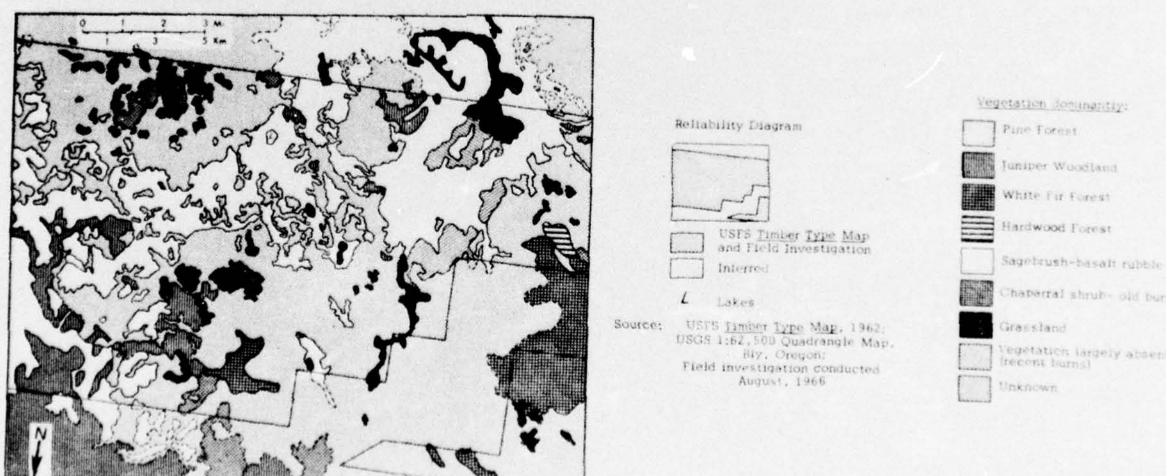

Figure K-6

Major vegetation types at Horsefly Mountain, Oregon (boundaries corrected to geometry of radar imagery).

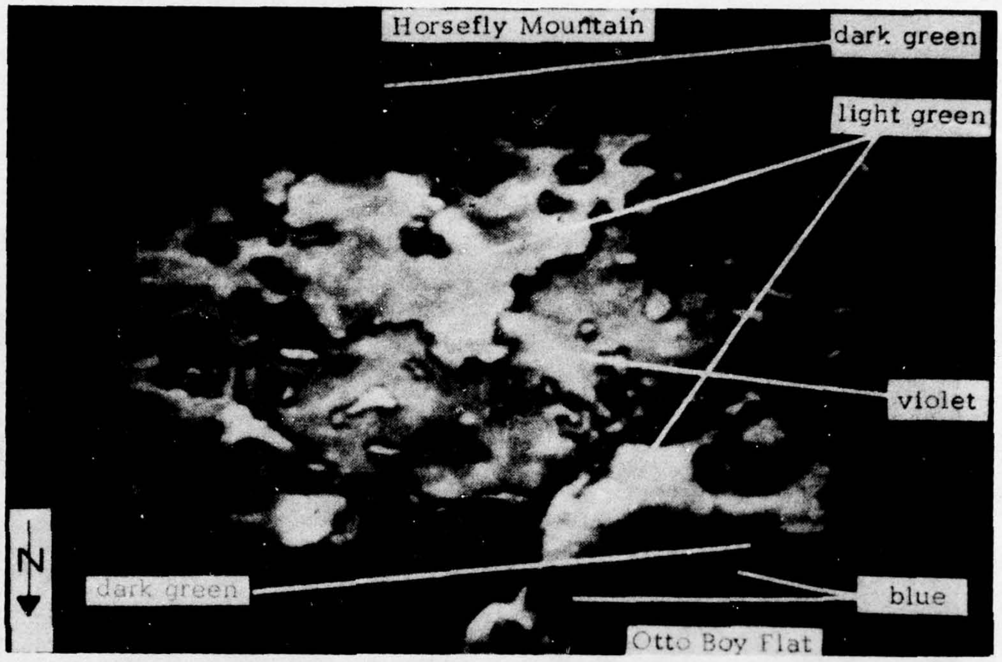

Figure K-7

Color combination of HH and HV radar image with map overlay.

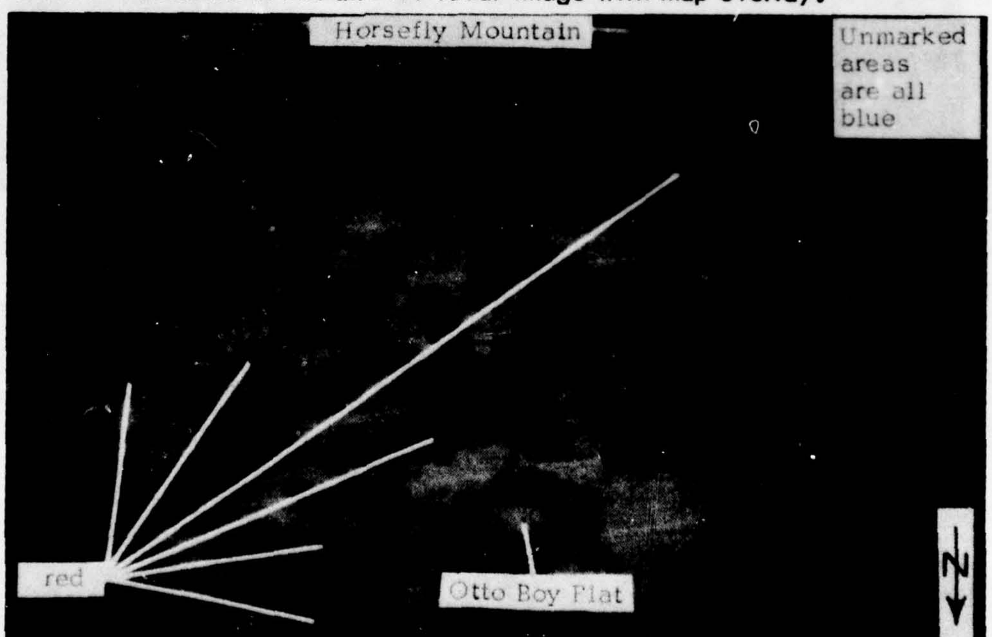

Figure K-8

Cross-polarized (HV) radar image clipped at high intensity level.

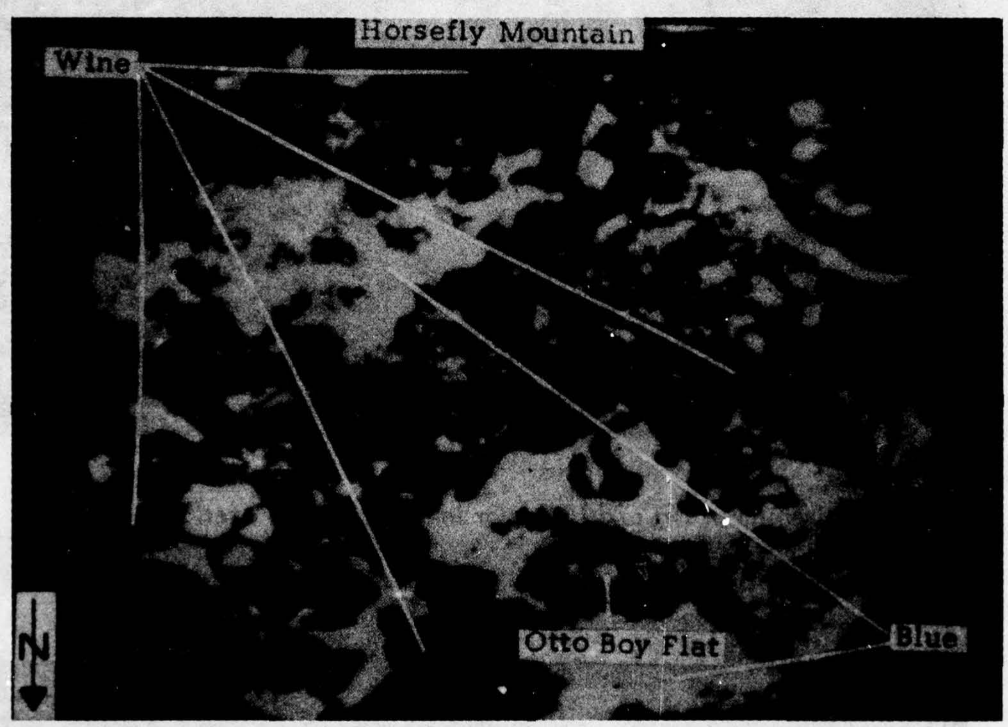

Figure K-9

Cross-polarized (HV) radar image clipped at low intensity level.

Some of the examples of applications of the IDECS described in the Multi-Image Correlation Systems Study (Dalke, 1967[46]; Dalke, 1968[47]; Dalke and Estes, 1968[48]), which is the most complete analysis of IDECS use, can best be understood in terms of a nomenclature shown in Figure K-10, (Dalke, 1968)[49]. The use of differentiation is shown in Figure K-11 where the T = 10 means the time constant of the differentiator was 10×10^{-7} sec. The area shown is an APQ-97 radar image of Wheeler Bay, Oregon. A level selection of this area is shown in Figure K-12. Combinations of level selections and edge enhancements are shown in Figures K-13 and K-14.

The applications described above used monochrome displays. An interesting application of the combination of radar and photography to produce color enhancements was performed with APQ-97 images and multi-spectral photographs of an area near Baldwin, Kansas. * Figures K-15 and K-16 are straight color combinations of multispectral photography and HH polarized K-band radar. Figure K-15 has Itek multiband image #5 shown in blue and radar shown in green. The river channel, temporary marshland, and other areas of extremely high soil moisture content are highlighted in shades of light blue. The green shows areas under cultivation and riparian vegetation at the time of the radar imaging. By adding Itek multiband images 2 and 8, additional information is shown in Figure K-16. The meander scar is highlighted along the dark green-yellow border in the lower center of the processed image, and geomorphic changes in the river channel are evidenced by the overlapping dark green lines of the meander on the left side of the processed image. Figure K-17 shows a similar example where the radar image was edge-enhanced before combination. Such analyses could be of value in determining fording and bridging potential for streams. Depending upon the character of the needed information, varying combinations may be utilized to provide unique data.

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[46] Dalke (1967). op. cit.

[47] Dalke (1968). op. cit.

[48] Dalke and Estes (1968). op. cit.

[49] Dalke (1968). op. cit.

* The reader is reminded that colors described relate to the original slide.

- The square represents either an input image or output display.

- The oval or circle represents an image transformation.

EAG - An Electronic, Additive, Grey-level display subsystem is represented by this symbol. The matrix parameter was not specifically recorded, a plus or a minus sign is used to indicate whether a positive or a negative of that input was added into the final display.

EEG - An Electronic, Edge-enhancing, Grey-level display subsystem is indicated by this symbol. In the IDECS system, this represents differentiation, with an electrical time constant of 10×10^{-7} seconds.

ELG - An Electronic, Level-Select, Grey-level display subsystem is represented by this symbol. The approximate position and aperture of the level-selected region in terms of the density range is indicated by the sketch above the input line, density decreasing to the right. The blackened region represents an uncalibrated approximate position of the level selected region.

Figure K-10

Nomenclature used by Dalke to describe enhancement operations performed on the IDECS.

Original

Image — Display

Enhanced

T = 10

Image — EEG — EAG — Display

Figure K-11

Example of use of edge-enhancement by differentiation on IDECS. A cross-polarized AN/APQ-97 image of the Wheeler Bay, Oregon, area is shown. Time constant of video differentiation was 10 x 10 -7 sec.

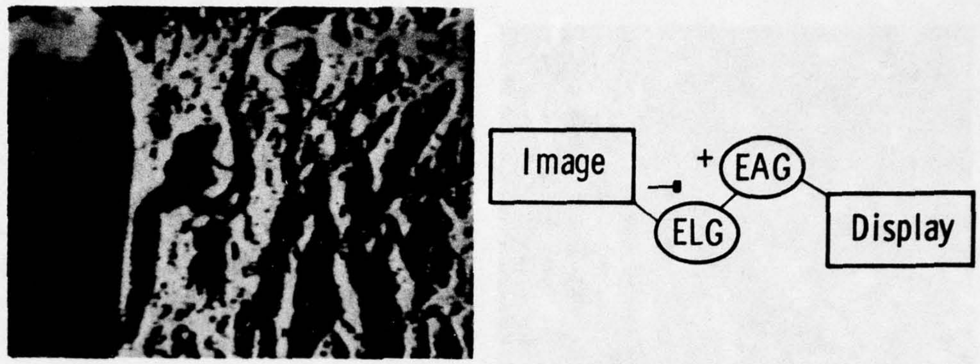

Figure K-12
Example of use of level selection on IDECS using same base image as Figure K-11. Lighter areas have been enhanced by the level-selecting process.

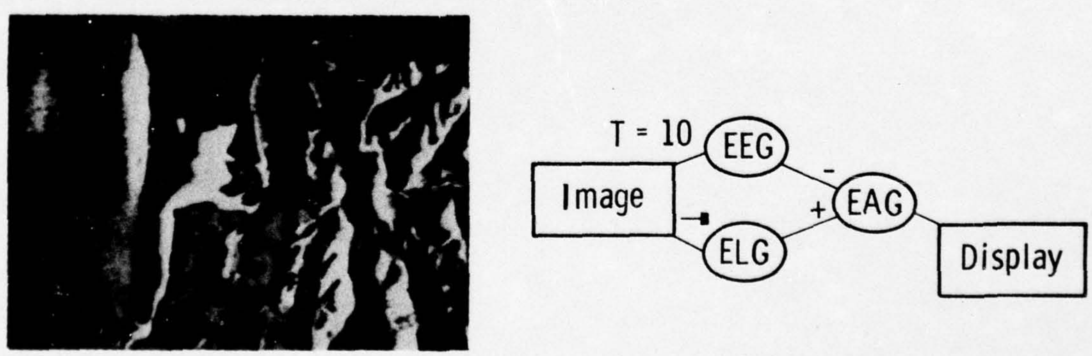

Figure K-13
Example of combination of level selection and differentiation (edge-enhancement) on IDECS using same base image as Figure K-11.

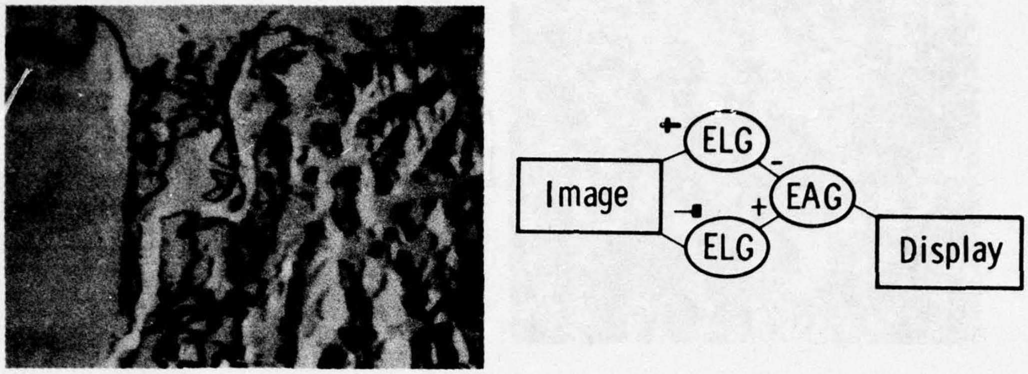

Figure K-14

Example of adding a positive and negative output of level selections at different levels on IDECS using the same base image as Figure K-11.

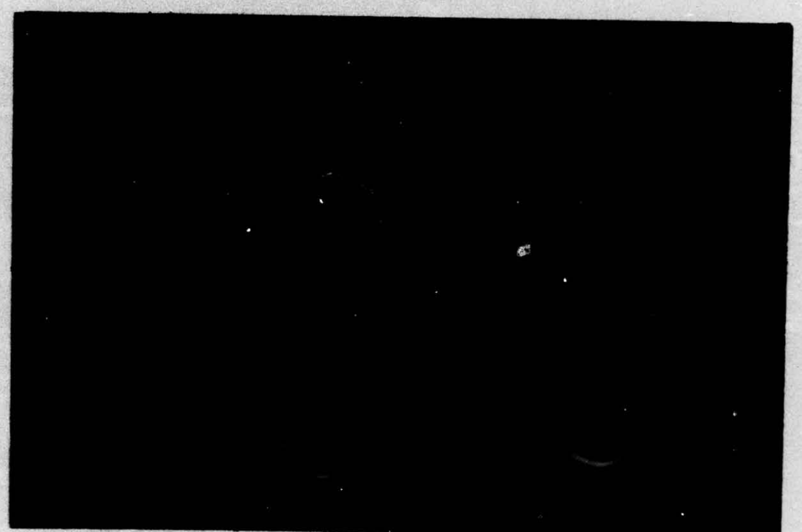

Figure K-15

Example of color combination on IDECS of radar and photographic images. Area near Lawrence, Kansas. AN/APQ-97 HH-Polarized radar image in green and Itek multiband camera image band 5 in blue.

Figure K-16

Example like that of Figure K-15 with Itek bands 2 and 8 instead of band 5.

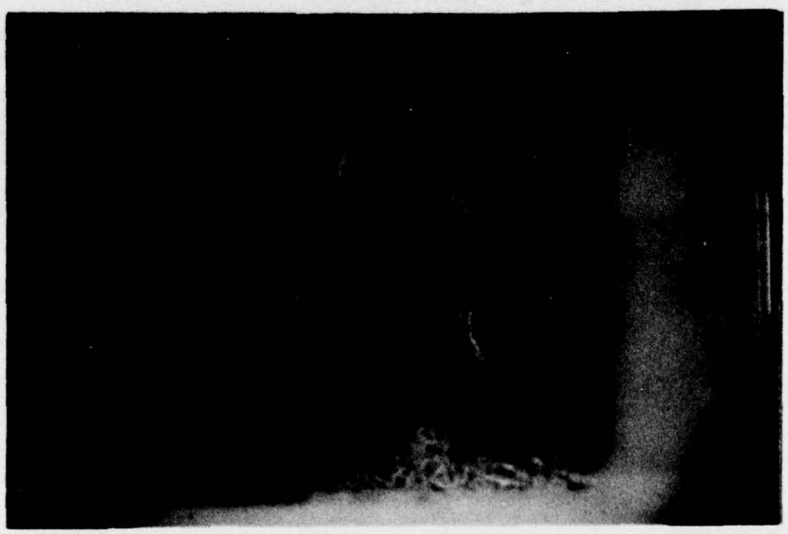

Figure K-17

Example of use of enhanced image in color combination on IDECS. Negative of Itek multiband image (band 8) shown in yellow-brown and edge-enhanced radar image shown in blue.

In recent investigations into the usefulness of high resolution radar for vehicle identification, it was demonstrated that the pseudo three-dimensional display was a valuable aid in comparing relative brightnesses.* In situations where a cluster, or sometimes ordered array, of highly reflective objects was to be analyzed, it was found to be exceedingly difficult to discriminate among the returns when using a monochrome display (either film or video). Isodensity contours presented in color on a television monitor would appear as small bulls-eyes and were also difficult to characterize. The pseudo three-dimensional display, however, presented an easy format for the human to work with. In one instance, where a selection of military equipments had been laid out in a random fashion within a regular array of corner reflectors, it was possible not only to separate the objects from the corner reflectors, but also to categorize them into meaningful groups. The ability to do this discrimination is dependent upon having sufficient dynamic range in the bright end of the signal. The importance of letting the operator have access to a larger dynamic range than is captured on conventional film is discussed below.

In another instance the pseudo three-dimensional display was shown to be very useful in examining a group of ships in a harbor. The radar return from the superstructures of several ships could best be compared with this display. With the aid of traditional ancillary information about ships, various classes and types were classifiable.

The IDECS with digital input from the PDP 15/20 computer has recently been used to produce simulated radar images, based on ground truth data and on measured APQ-97 mean intensities for that category. Such a simulation of an APQ-97 image of the Garden City test site is shown in Figure K-18. Although this is not an actual radar image, it demonstrated the possibilities of combining digital processing of radar images with IDECS display. An interesting potential application of such a technique would call for preparation of a forecasted image for a particular flight based on either ground truth or the status observed on a previous flight. An interpreter could then tell at a glance which areas differ in the newly produced image from what was forecast, thereby calling attention to regions where more extensive interpretation of other sensors, obtaining of ground truth, etc., would

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* Two dimensions are spatial, the third is intensity. For each single line this is like a radar A-scope display. Thus, the 3-D display is like a multiple A-scope display showing radar returns from an area rather than from a single line.

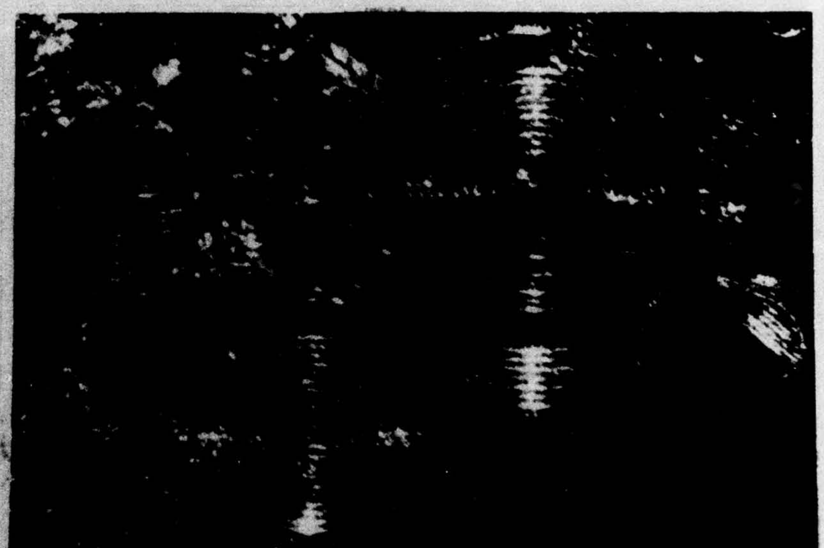


Figure H-1. Sun City, Arizona, Strategic Air Command Imagery.

be necessary. Since the IDECS can readily be used as a change detector, these areas of more than ordinary interest could be pinpointed automatically and, for example, presented in red on a monochrome background image.

To illustrate the potential of polychromatic (multifrequency) radars, data collected by the MAS (microwave active spectrometer) were used to produce simulated images of an agricultural scene for three frequencies (8.6 Ghz, 13.8 GHz, and 16.2 GHz). These simulations were combined in color, as shown in Figure K-19. Here red was assigned to 8.6 GHz, green to 13.8GHz, and blue to 16.2 GHz. Because of differences in the mean level of signals in the different frequency bands, color images produced by assigning the same mean intensity level in the radar to the same mean intensity level for each color tend to be monochromatic. Hence, the image shown was made by assigning the mean intensity observed by the MAS for the frequency assigned to red to a mean red level, and similarly for the other colors. This produces the maximum color contrast between areas with different composition on the ground.

Conclusions

The growing complexity and amount of sensor data, the time sensitivity of tactical information and the already developed state-of-the-art all point to a conclusion that automated assistance to the analyst is required and feasible. State-of-the-art systems can be available now. Optimized stations would require about a 3 year development effort. Doctrine and techniques and training must be developed concurrently. Specifically: a sophisticated image analysis system is required which has as its focus a completely interactive machine-aided interpretation station. That is, the analyst would perform his basic tasks in a conventional manner, on a light table interfaced to analog and digital machines in such a way that all machine aided operations could be called by single or a minimum set of keystrokes on his control panel. Results would be displayed on high resolution TV monitors as well as hard copy outputs. The light table itself would serve as an input along with "library" data and images from related sensors. Operations similar to those described earlier in this appendix would be implemented in analog, digital and optical systems. In summary, the elements of an automated analysis station are:

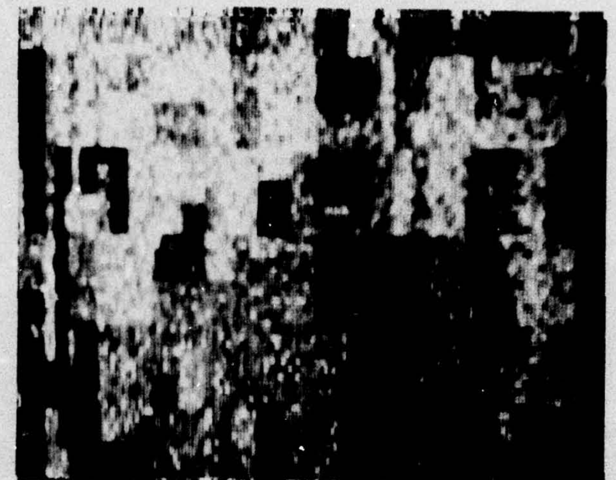
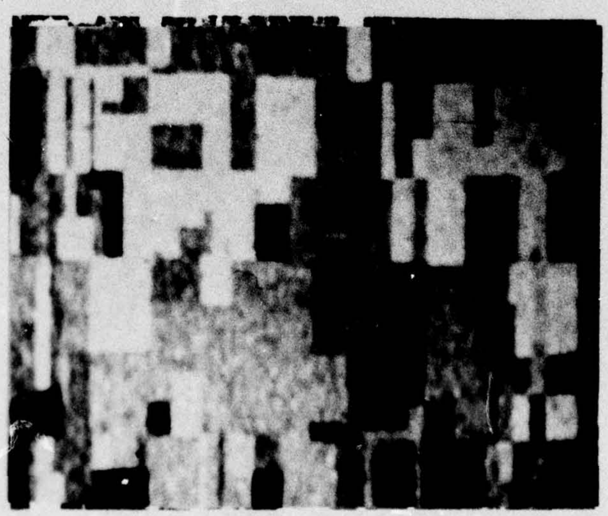


Figure K-19 a and b
Color simulation of an agricultural scene as it would be seen by a multifrequency radar. 8.6 GHz is red; 13.8 GHz is green; 16.2 GHz is blue. Figure K-19a is an HH simulation and Figure K-19b is a VV simulation. Microwave ground-based spectrometer data used to determine intensities at the three frequencies. Different crops show up as follows:

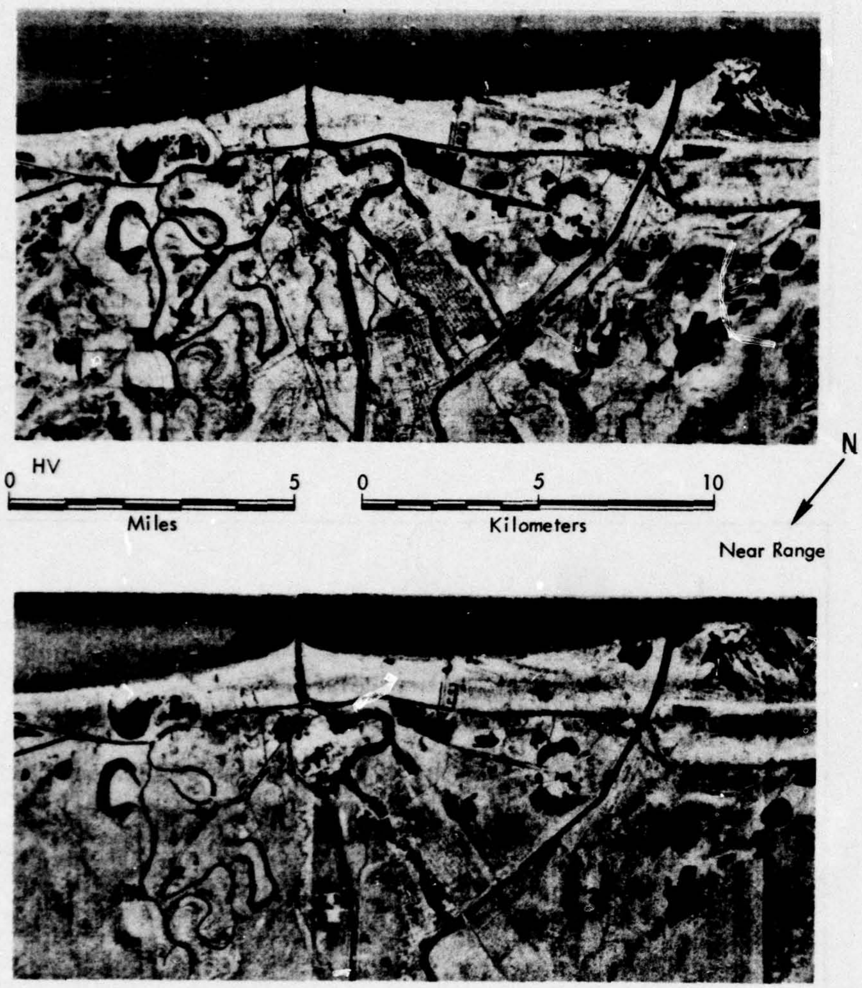


Yellow - wheat stubble
Light blue - tall alfalfa
Dark green - short alfalfa
White - short milo
Light green - tall milo
Orange - tall soybeans
Red - green wheat

1A

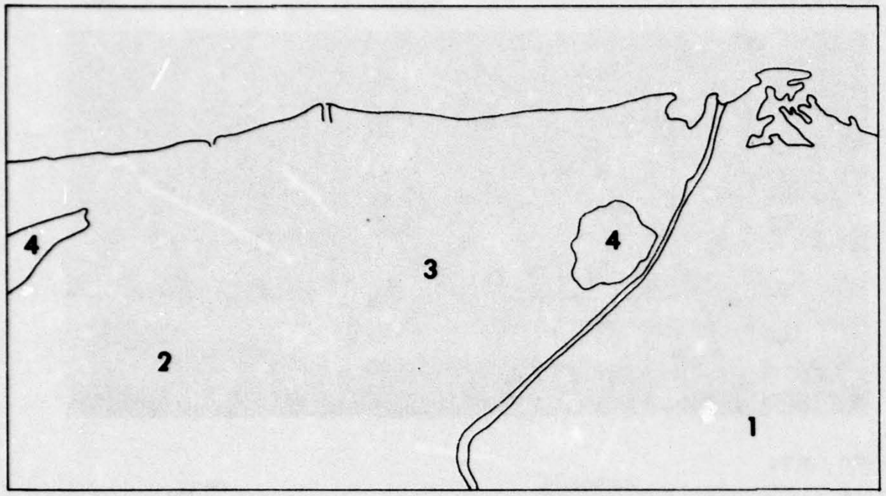
FREEPORT, TEXAS

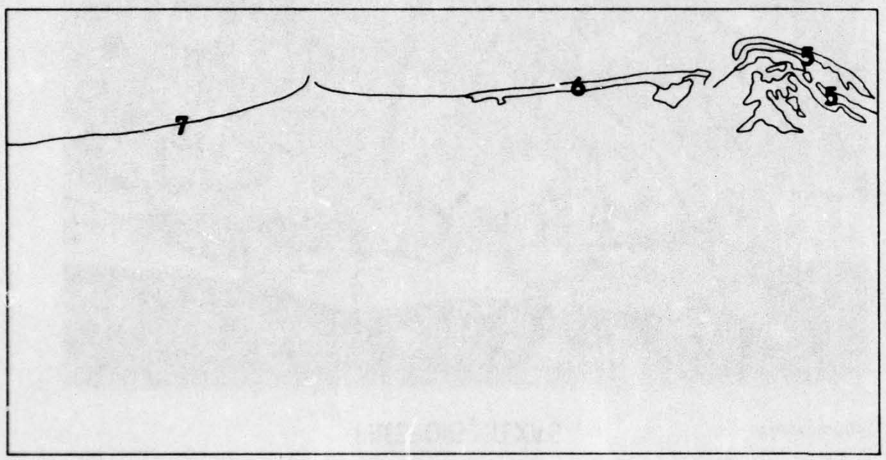
Near Range



HH

AN/APQ-97
K-band





IA

CROSS COUNTRY MOVEMENT
FOR TROOPS AND VEHICLES

1 - Moderately Easy for Both Men and Equipment.

2 - Moderately Easy for Men, Moderately Difficult for Equipment Due to Man-made and Natural Obstructions.

3 - Moderately Difficult for Men and Equipment Due to Man-made and Natural Obstructions.

4 - Difficult for Men and Equipment Due to Wet, Swampy Nature of the Area.

NEAR SHORE CONDITIONS
AND LANDING SITES

5 - Offshore Mainly Submerged Alluvial Bars, Area Behind Bar of Irregular Small Bodies of Standing Water. Poor Offshore Landing Capability.

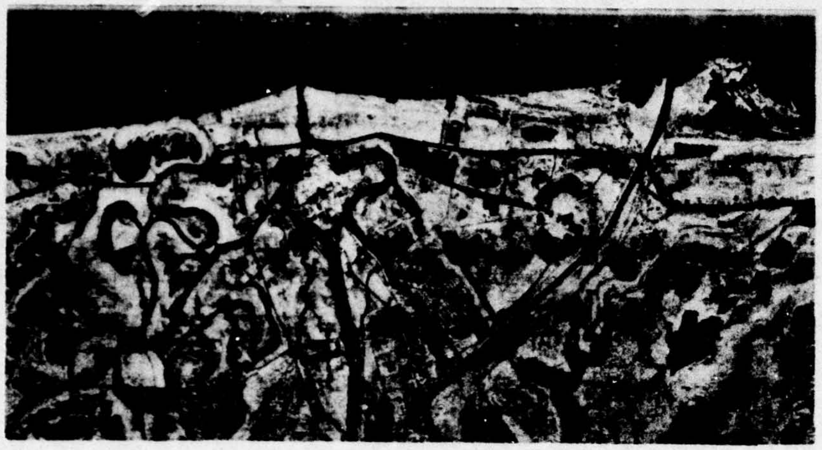
6 - Long Shore Partially Submerged Alluvial Bar, Capable of Supporting Offshore Troop Landing.

7 - Unobstructed Beach Zone, Capable of Supporting Landing of Troops and Equipment.

FREEPORT, TEXAS

Near Range

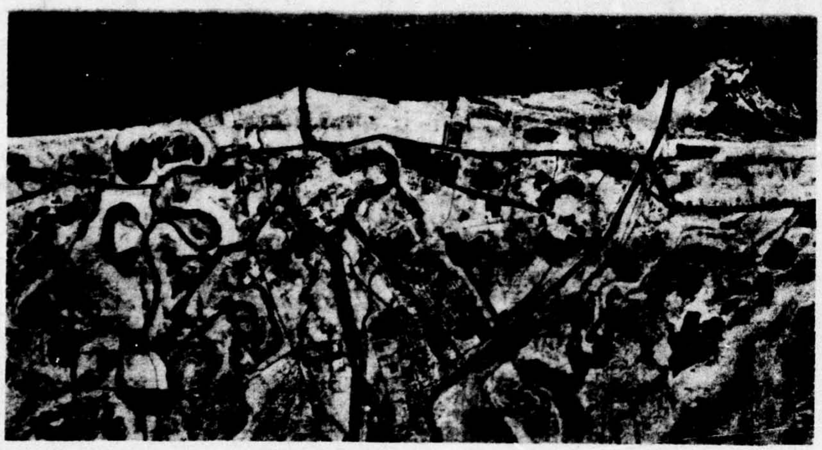
1B



HV

0 5 Mi 0 5 10 Km.

Near Range

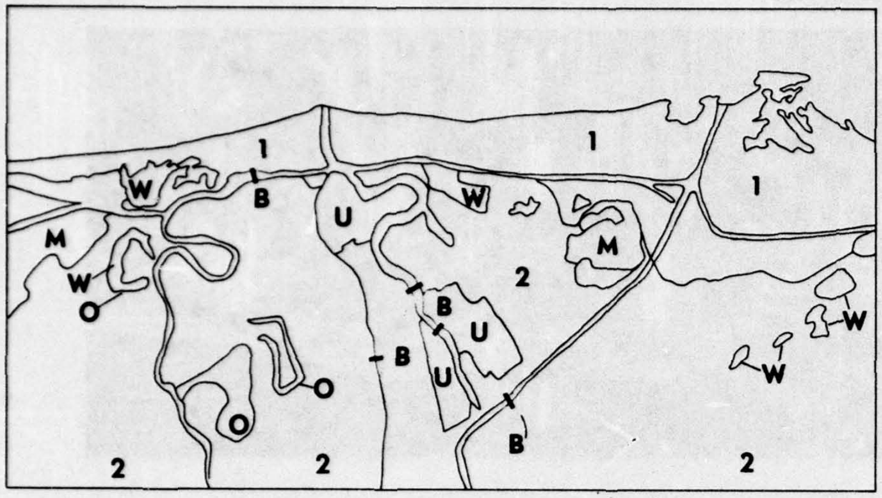


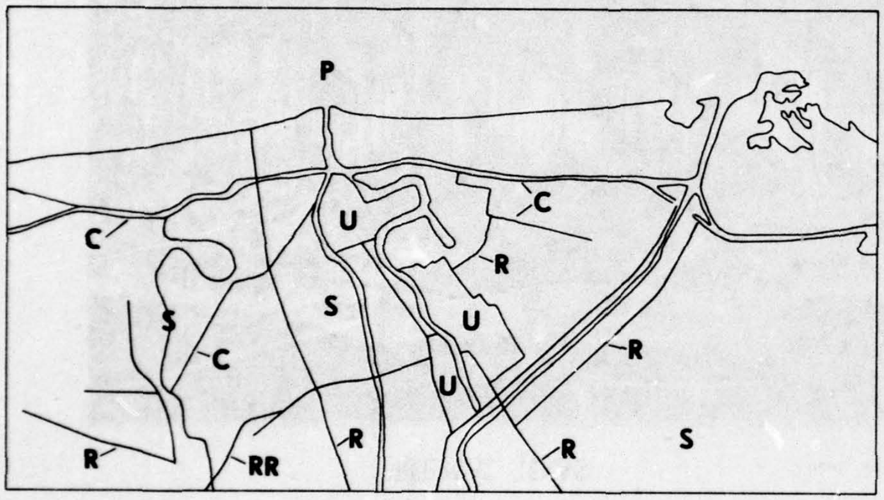
N

HV

AN/APQ-97
K-band

1 B





SURFACE CONFIGURATION

1 - Gently Sloping Unobstructed Beach.

2 - Gently Rolling Coastal Topography Covered by Herbaceous Vegetation. Water Courses and Water Bodies Provide Only Obstruction.

W - Standing Water.

O - Oxbow Lakes.

M - Marsh or Swamp with Some Standing Water.

B - Bridges.

COMMUNICATION NETWORK

R - Roads and Highways.

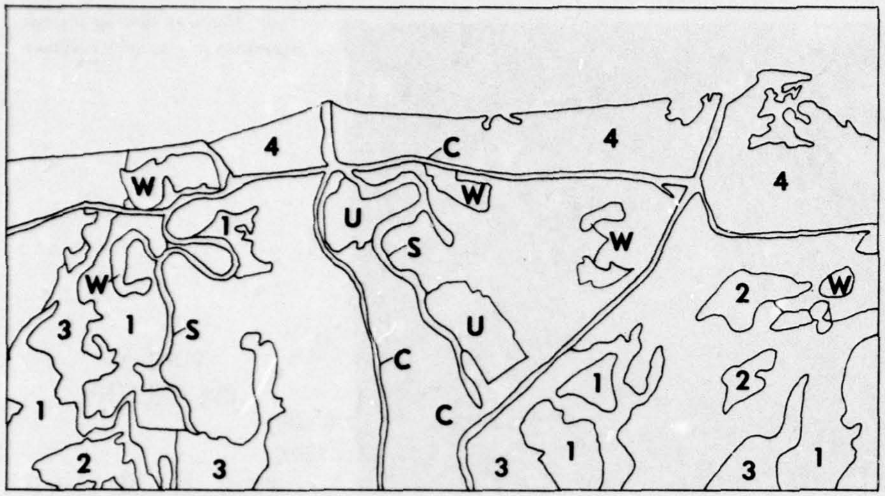
U - Built-up Area, Residential and Industrial with Regular Road Networks.

RR - Railroads.

P - Protected Offshore Channel to the Sea.

C - Canals

S - Streams



VEGETATION AND CONCEALMENT

1 - Dense, Herbaceous Vegetation in Topographically Low Areas, Capable of Concealing Scattered Individuals.

2 - Medium Dense Herbaceous Vegetation on Relatively High Areas, Limited Concealment Capabilities.

3 - Short to Medium Herbaceous Vegetation of Medium Density, Poor Concealment Capabilities.

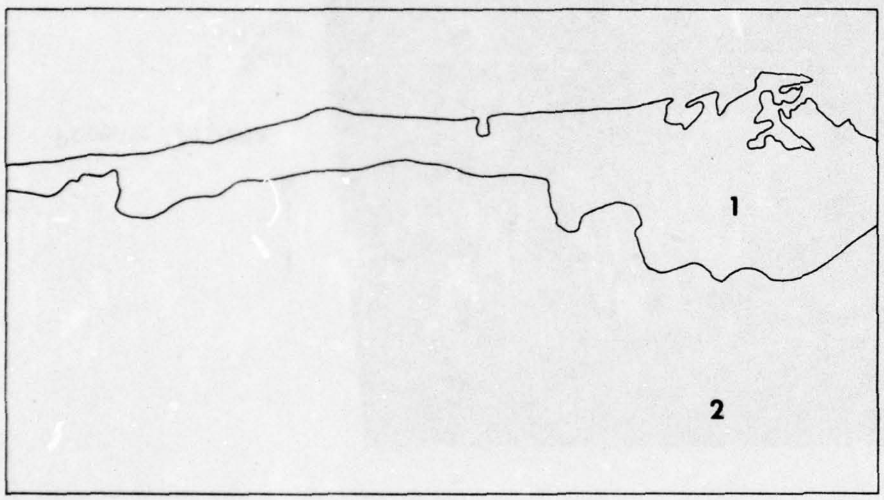
4 - Beach Vegetation Consisting Primarily of Relatively Small Patches of Medium Tall Grasses, No Concealment Capabilities.

U - Built-up Area, Unvegetated.

S - Natural Streams.

C - Canals

W - Standing Water.



SOIL AND SOIL DEPTH

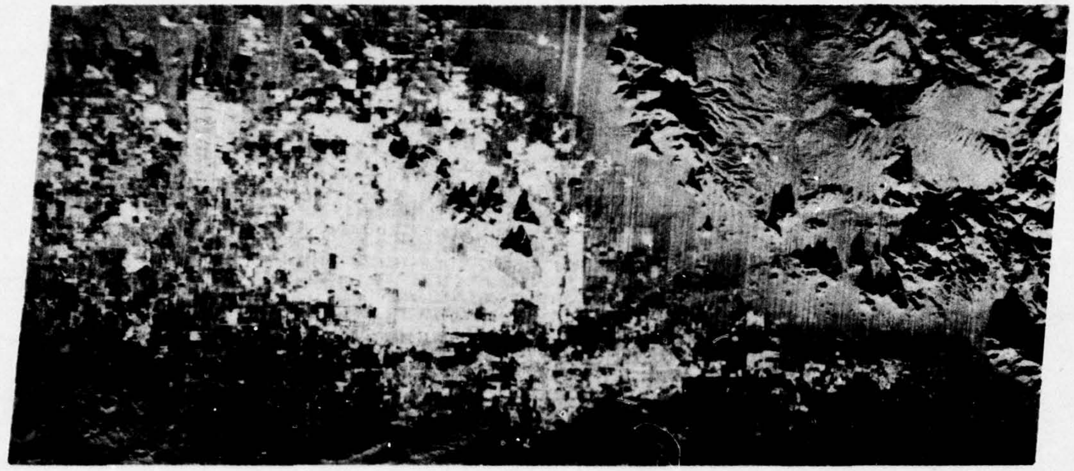
1 - Beach Sands, Unconsolidated, Depth Greater Than 15 Feet.

2 - Alluvial Soils of Fine Sediment, Depth Greater Than 15 Feet.

Phoenix, Arizona

N

Near Range



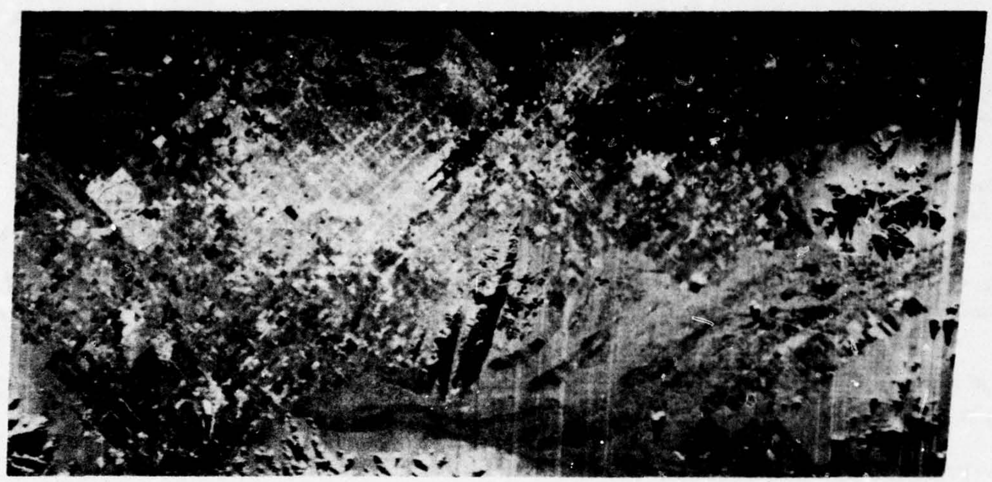
0 5 10 Miles

0 5 10 15 20 Kms.

Near Range

AN/APS-94D
X-Band

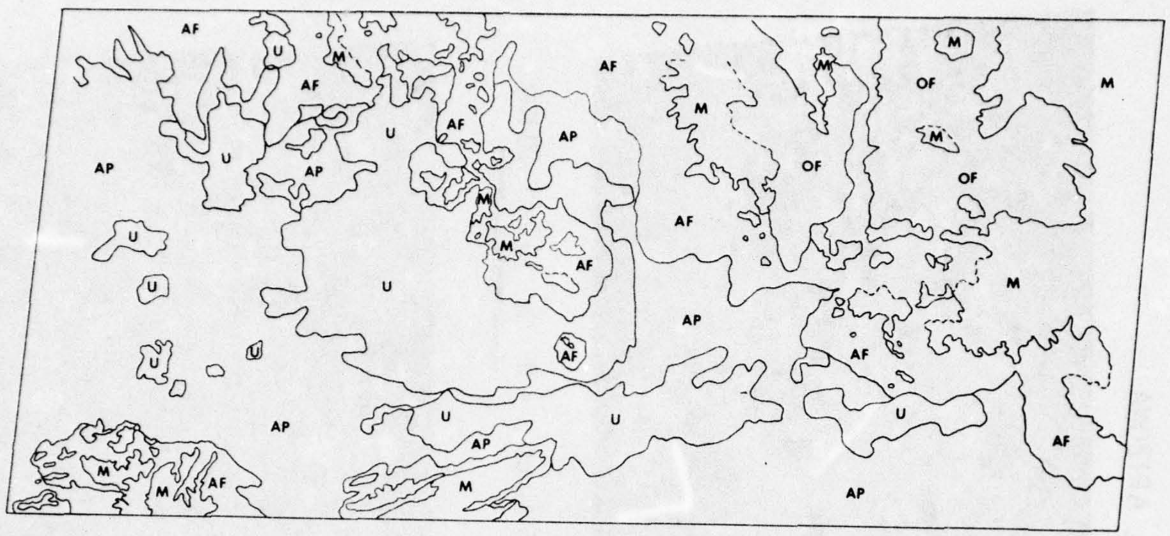
N



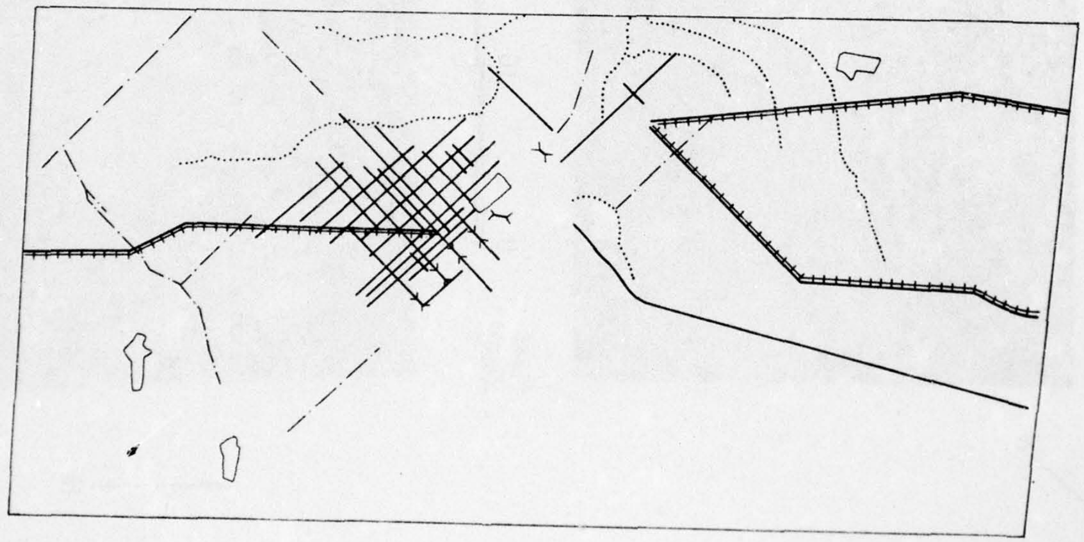
Imagery Courtesy of Motorola
Aerial Remote Sensing, Inc.

II

Surface Configuration
U = Urban
M = Mountains
AF = Alluvial Fans
OF = Older Fans
AP = Alluvial Plains

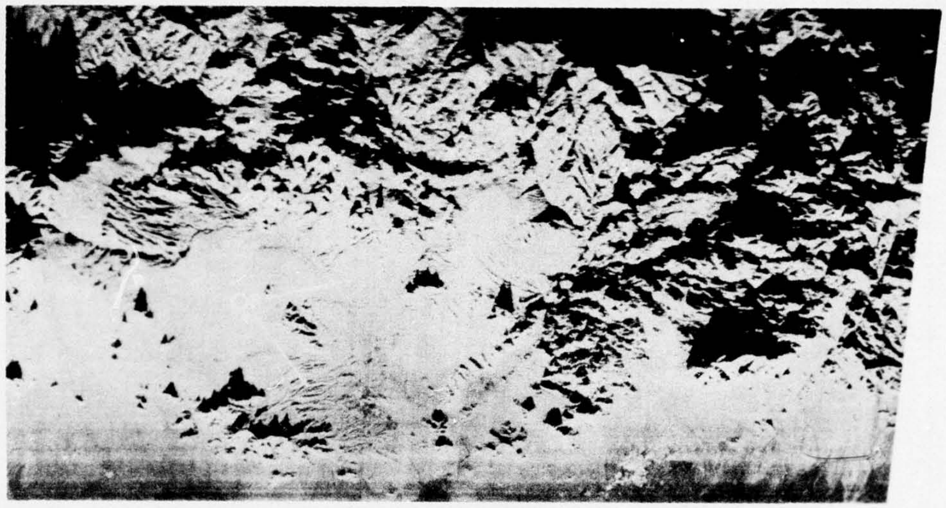


Lines of Communication
— Major Roads
Bridge
Power Line
Irrigation Canal
Railroad
Airfields



PHOENIX, ARIZONA

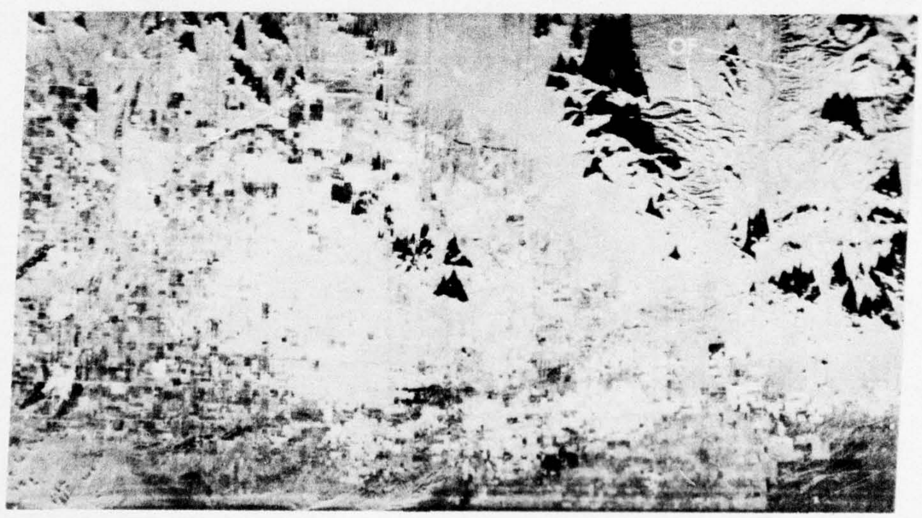
N



Near Range

0 5 10 15 Miles

0 5 10 15 20 Km.

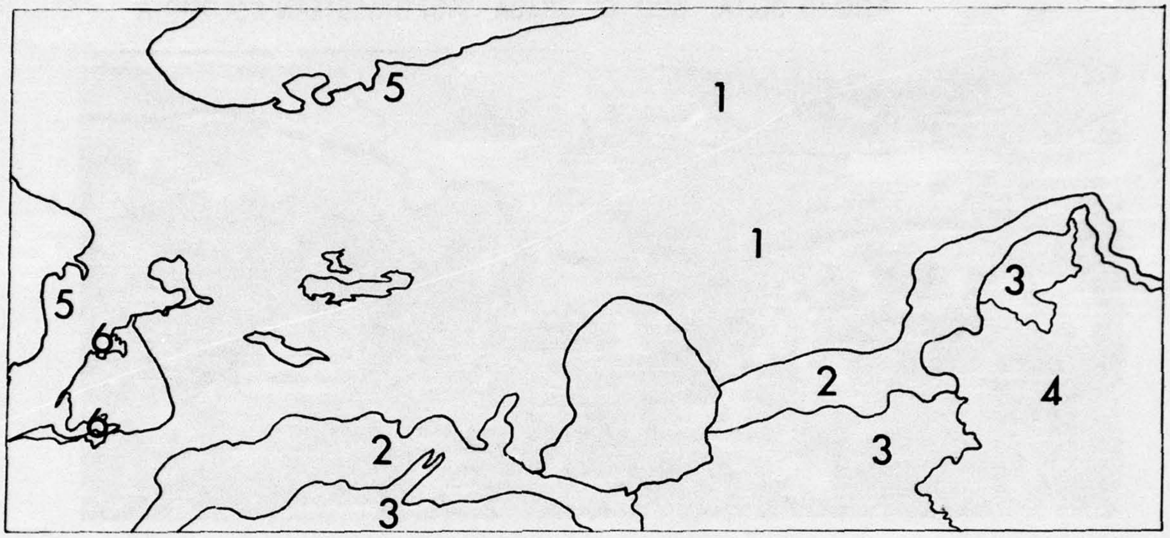


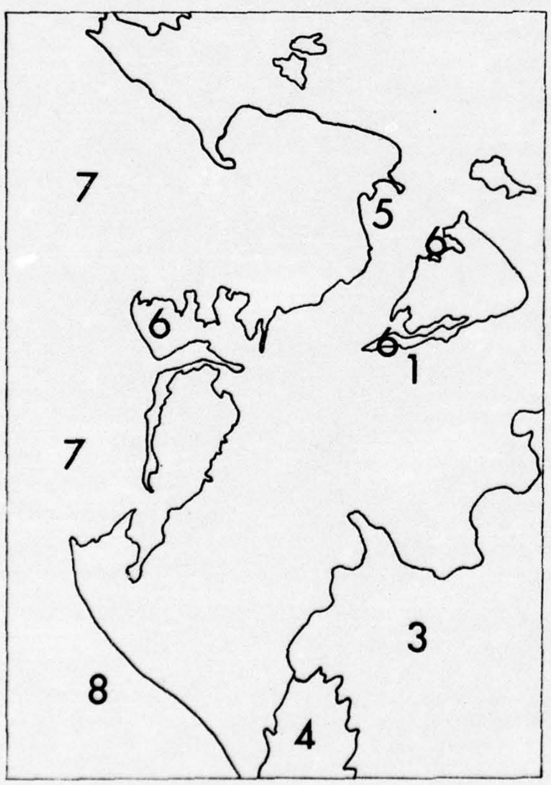
N

Near Range

AN/APS-94D
X-Band

Return Signal Contrasts in Alluvium Northeast of Phoenix - A Function of Look Direction and Range.





SOIL - TYPE AND DEPTH

1 - Alluvium > 20 Ft.

2 - Pediment Soils 10 - 20 Ft.

3 - Mountain Soils 5 - 10 Ft.

4 - Mountain Soils Less Than 5 Ft. Thick.

OFFSHORE FREATURES

5 - Mangrove Forest; Tree Roots in Standing Water.

6 - Unconsolidated Deep Alluvium in Near Shore Deltas.

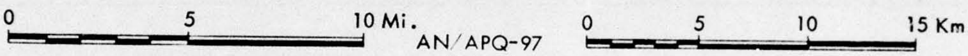
7 - Offshore Spit.

8 - Waves Breaking Alongshore.

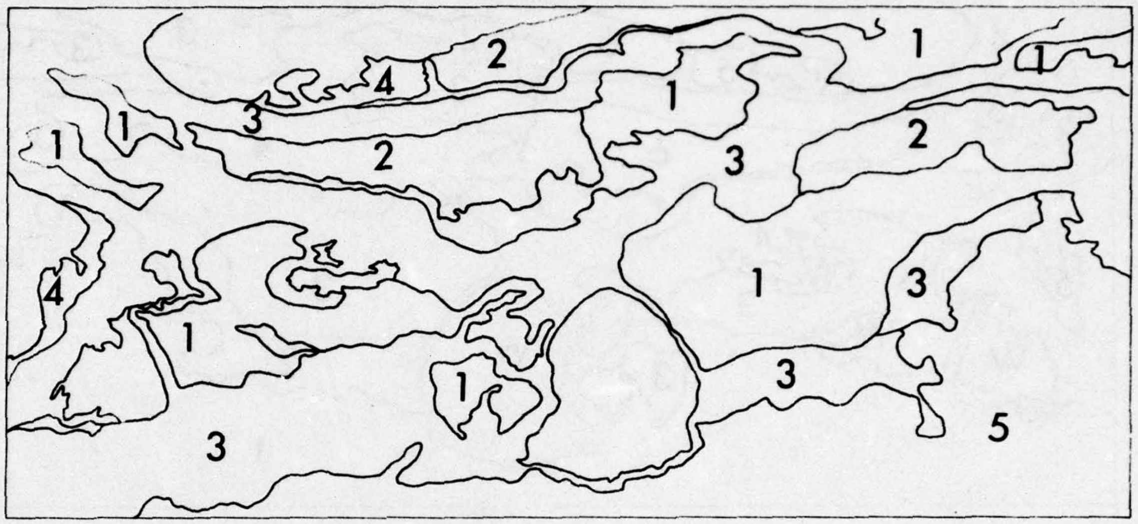
Near Range

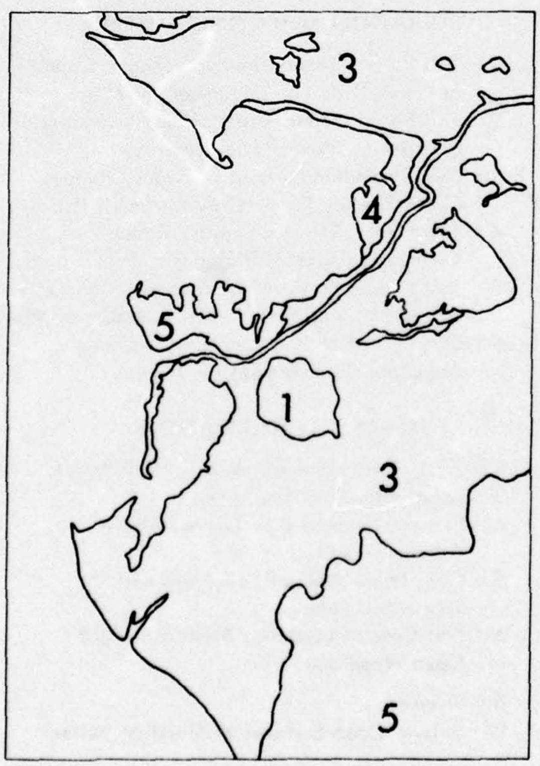
ATRATO DELTA, GULF OF URABA, NORTHWESTERN COLOMBIA

AN/APQ-97
K-Band



Near Range





CROSS COUNTRY MOVEMENT FOR FOOT TROOPS AND VEHICLES

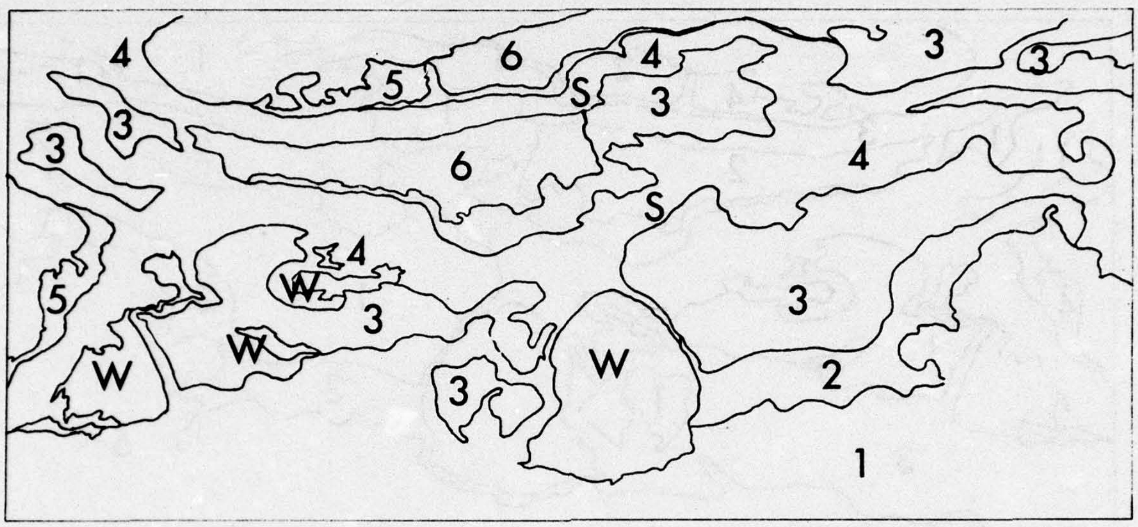
1 - Moderately Difficult for Foot Troops, Can Support Vehicles in Dry Season.

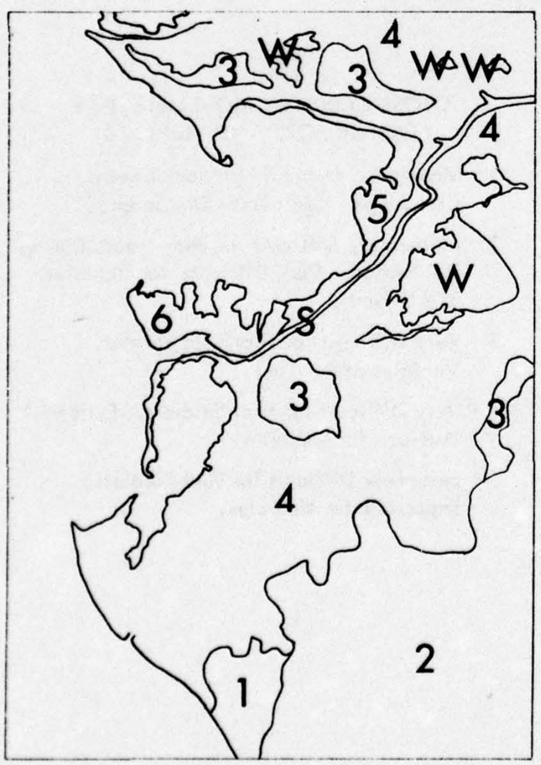
2 - Moderately Difficult for Foot Troops During Dry Season, Very Difficult for Vehicles at All Times.

3 - Very Difficult for Foot Soldiers and Vehicles at All Times.

4 - Very Difficult for Foot Soldiers, Extremely Difficult for Vehicles.

5 - Extremely Difficult for Foot Soldiers, Impossible for Vehicles.





VEGETATION AND CONCEALMENT

1 - Tall Forest, Discontinuous Canopy, Capable of Concealing Large Numbers of Men.
2 - Tall Forest, Continuous Canopy, Capable of Concealing Men and Equipment.
3 - Open Woodlands, Discontinuous Canopy, Could Provide Cover Only for Small Patrols.
4 - Tall Forest, Few Emergents, Capable of Concealing Several Platoons of Foot Troops.
5 - Tall Closed Forest of Mangroves, Can Only Provide Protection for Small Numbers of Men.
6 - Open Woodland, Discontinuous Canopy, Adequate Concealment for Troops.

SURFACE CONFIGURATION

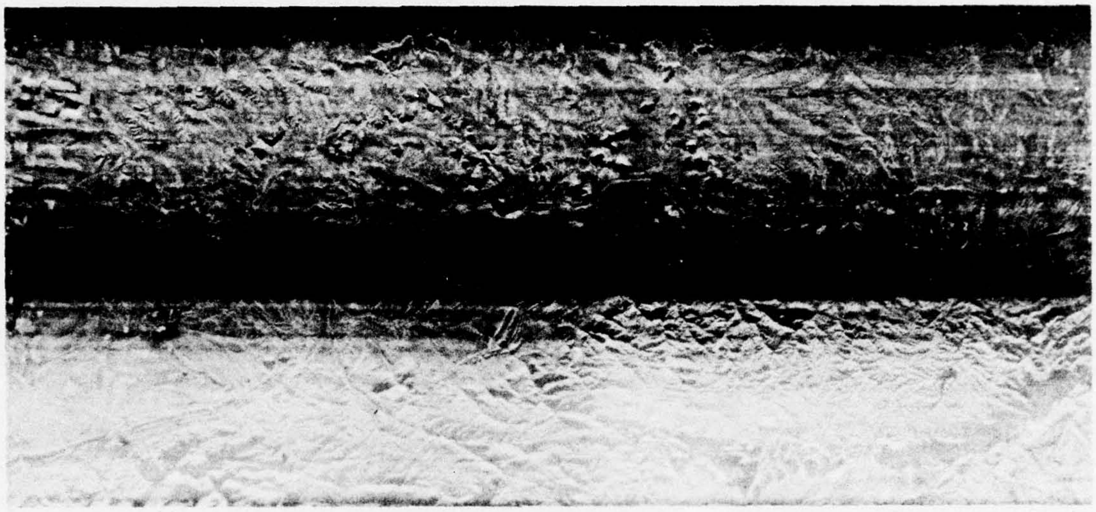
1 & 2 - Upland, Broken; Locally High Relief.
3 - Relatively Level Lowland.
4 - Natural Levees, 2 to 17 Feet Above Adjacent Land.
5 - Near Shore Area of Tall Trees with Submerged Roots.
6 - Flat Coastal Lowland, Medium Height Open Woodland.

S - Streams.
W - Inland Open Surfaces of Standing Water.

V

DENVER - COLORADO SPRINGS CORRIDOR, COLORADO

Near Range



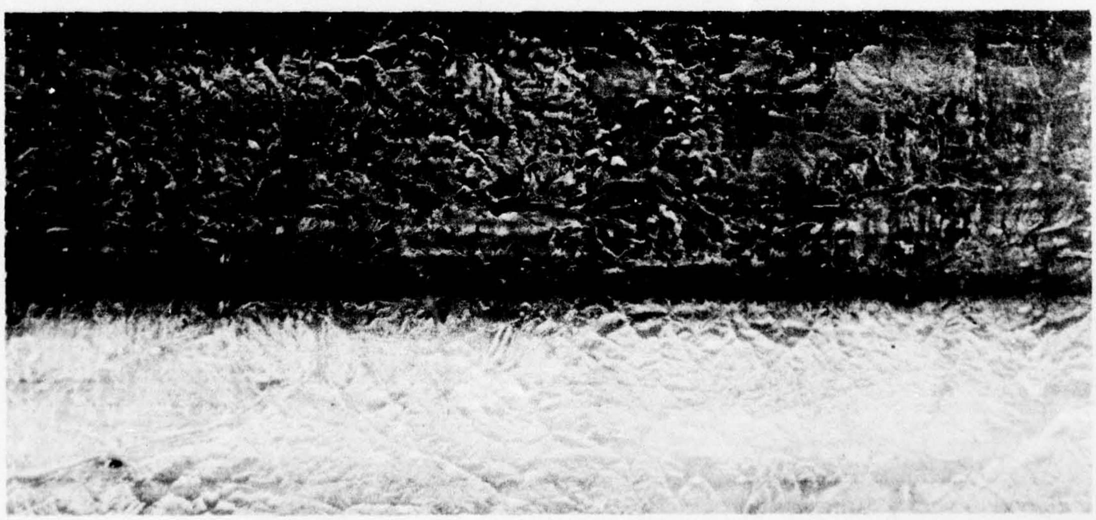
25 May 1972

0 5 10 20
Miles

0 5 10 20 30
Kilometers

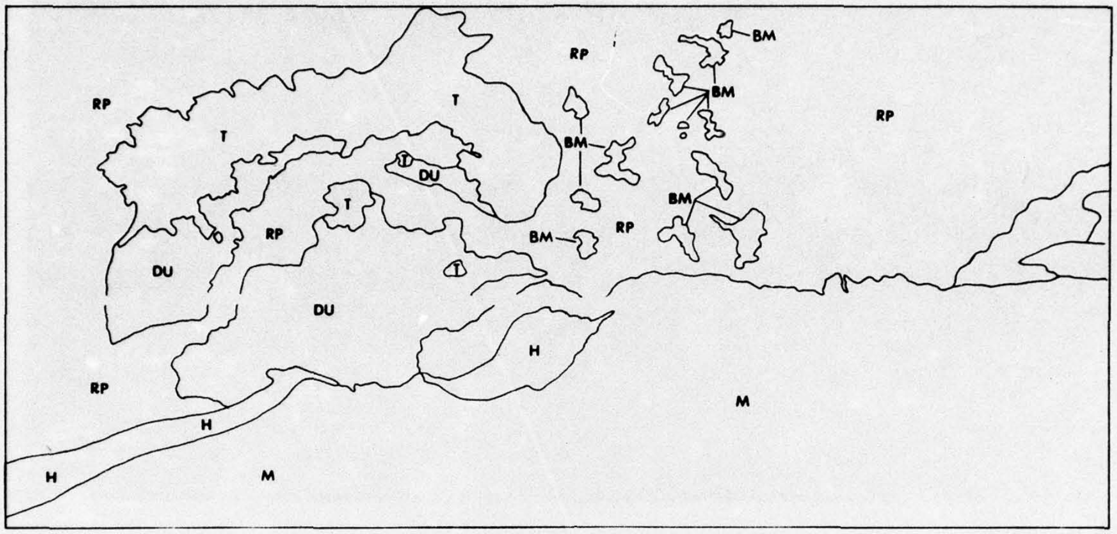
N

Near Range



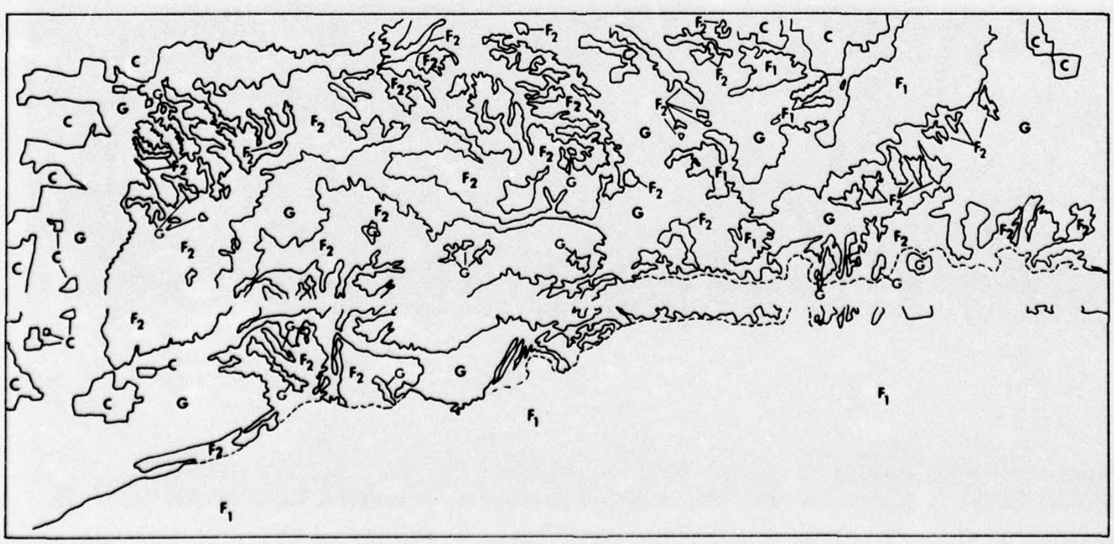
23 February 1972

SC-01
X-Band



SURFACE CONFIGURATION

RP - Rolling Plains
DU - Dissected Uplands
T - Table Lands
BM - Isolated Buttes and Mesas
H - Hogbacks
M - Mountains



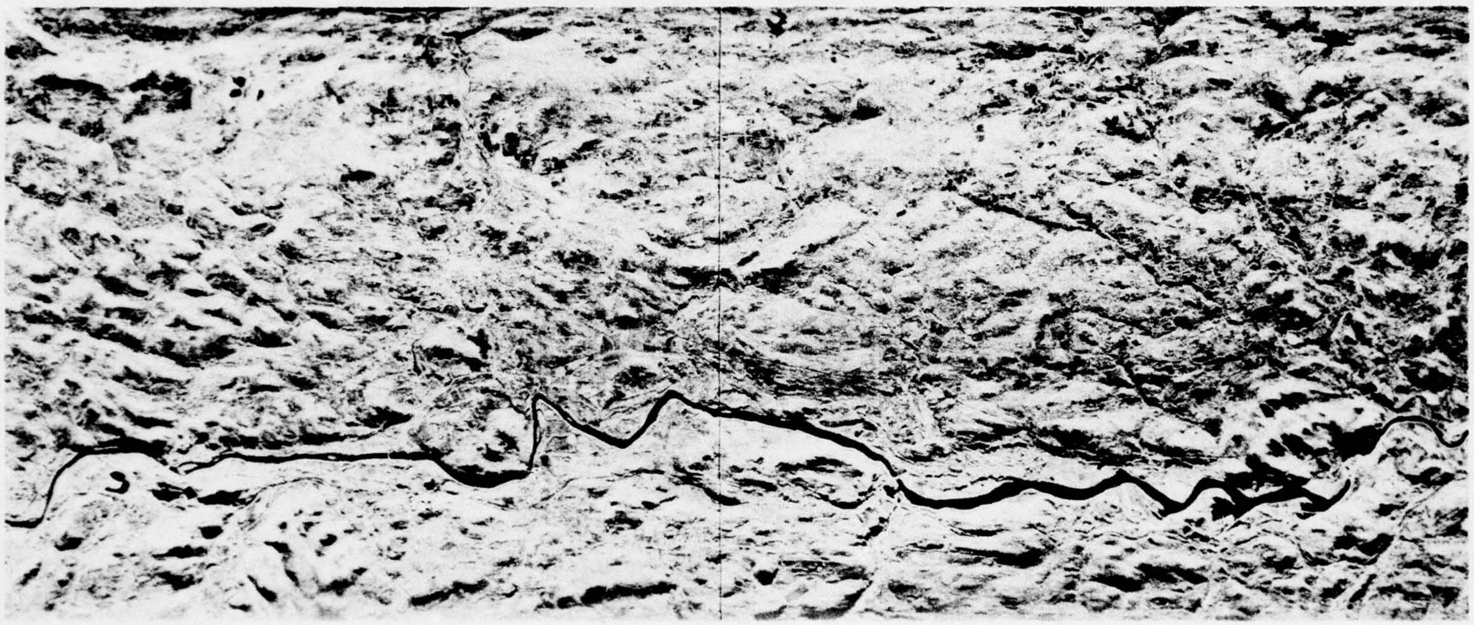
VEGETATION

F_1 - Tall Dense Forest
F_2 - Short Open Woodlands
G - Grassland
C - Cropland

VI

CONNECTICUT RIVER VALLEY, NEW HAMPSHIRE AND VERMONT

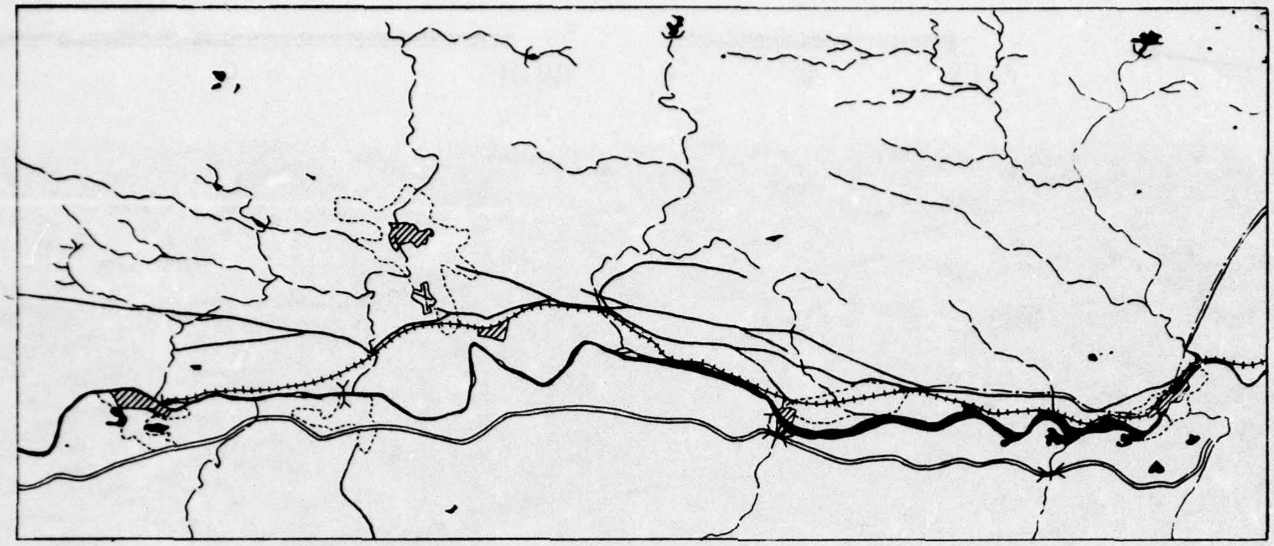
Near
Range



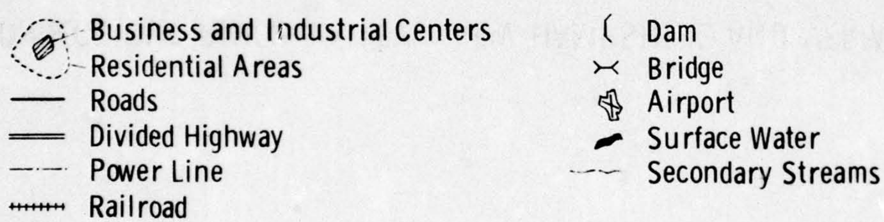
0 5 10 Mi. 0 4 8 Km.

N

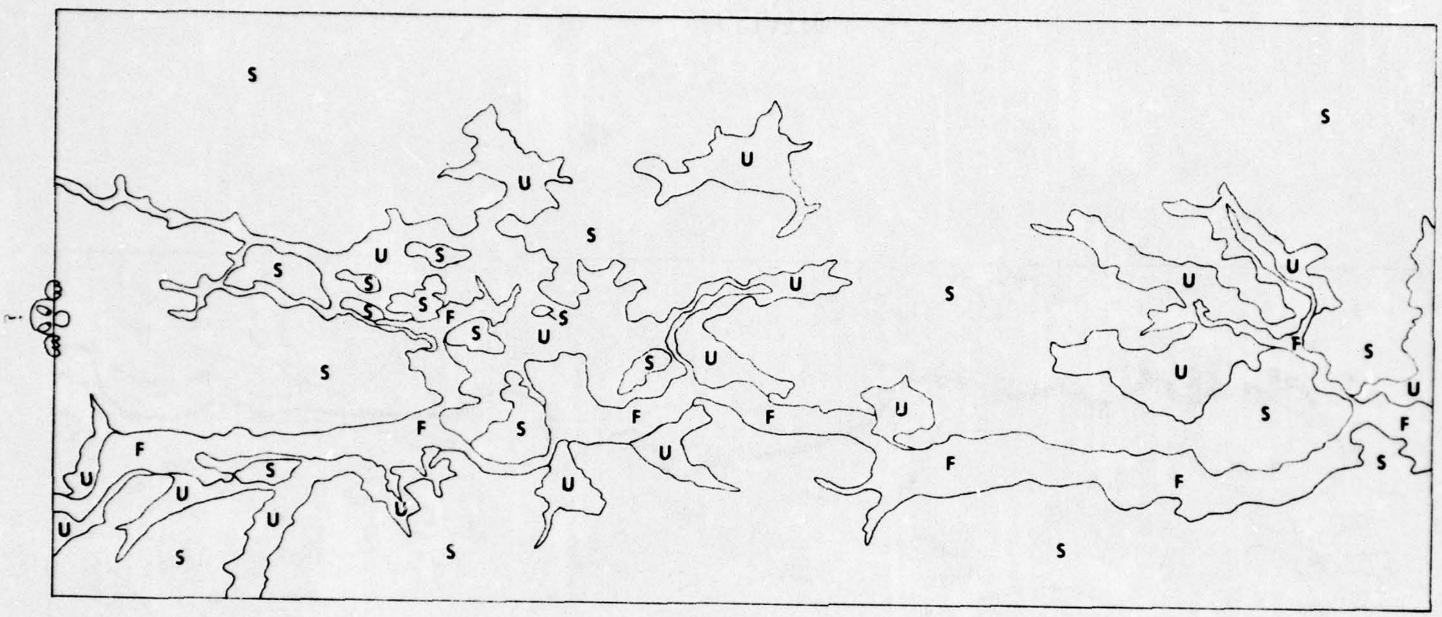
AN/APQ-97
K-Band



LINES OF COMMUNICATION AND URBAN PATTERNS



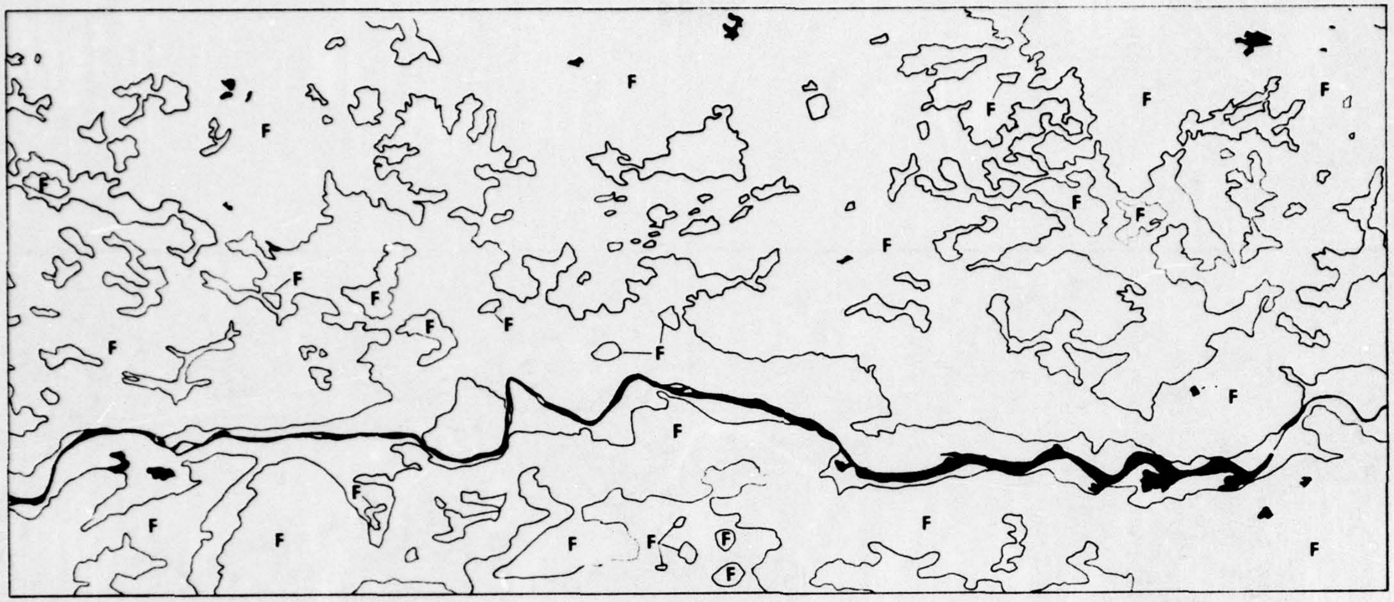
VI



SOILS

S - Shallow Rocky Soil
U - Upland Fine Grained Soils, Including Terraces
F - Floodplain Deposits

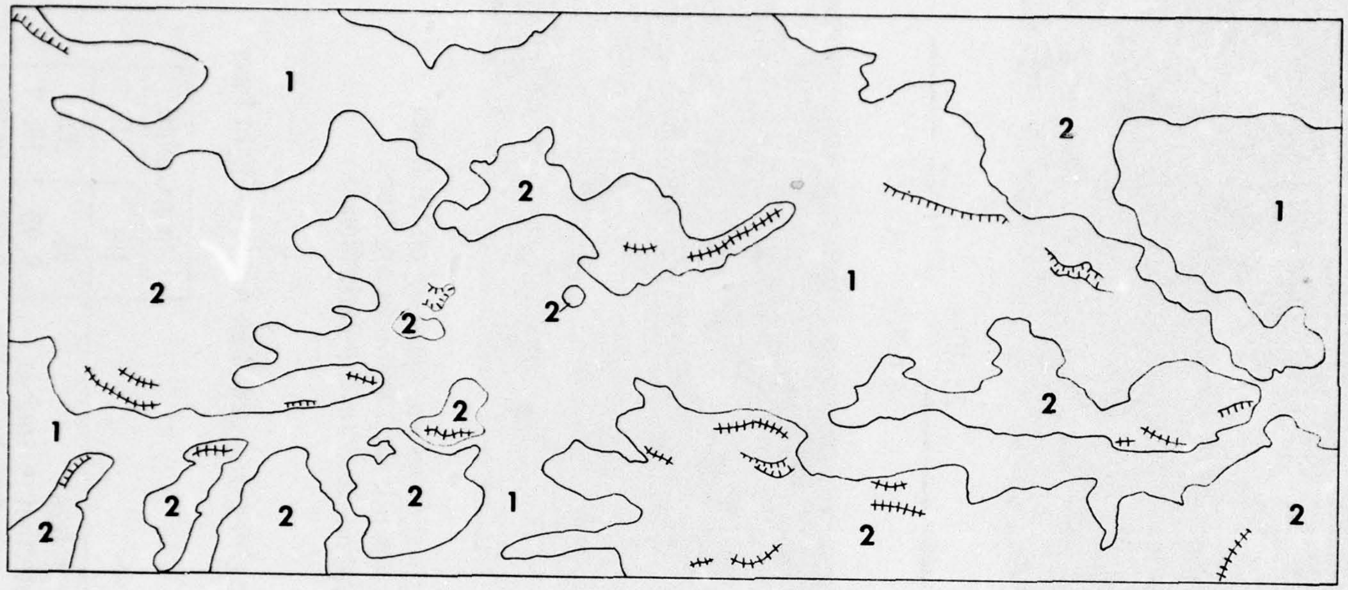
VI



VEGETATION

- F - Forest
- Nonforest
- Water

VI



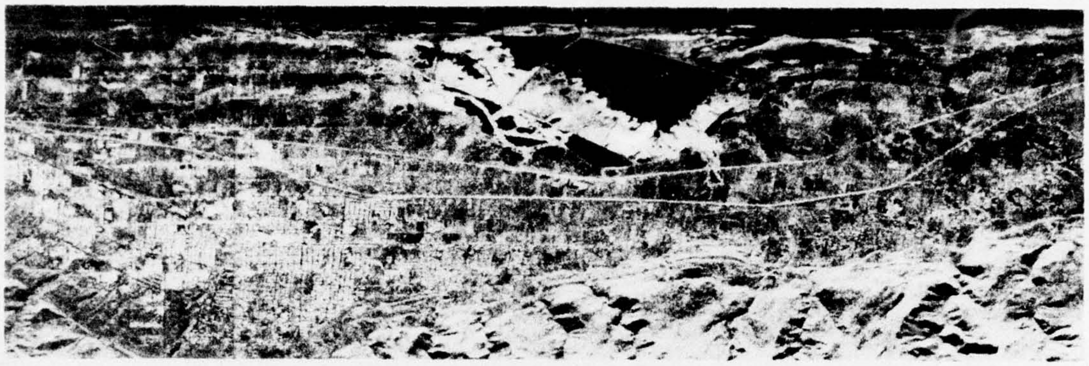
TERRAIN SLOPE

1 - Level or Gently Sloping Terrain
2 - Areas with Slopes Greater than 20%
Ridges with Slopes Greater than 40%
Escarpments with Slopes Greater than 40%

BOUNTIFUL, UTAH

VII

Near Range



HH

0 2.5 Miles
0 4 Km.

N ⟶

Near Range

HV

Urban and Industrial Areas are Apparent on HH (Like) Polarization. Communication Networks are More Accurately Mapped on HV (Cross) Polarization.

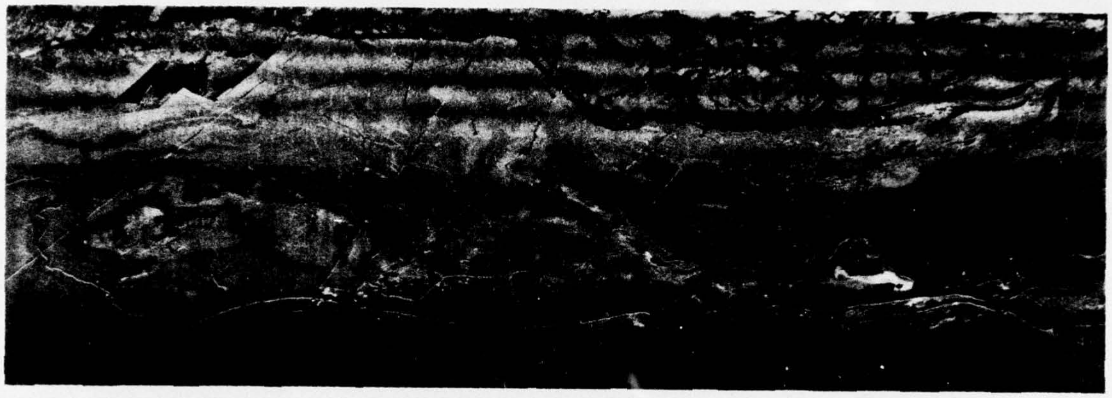
Detection of Power Lines Oriented at an Angle to Flight Pass

	Polarization	
	HH	HV
Number of Interpreters	35	33
Total Positive Detection in Inches	9.98	133.9
Average Positive Detection in Inches	0.28	4.04
Percent Positive Detection	3.50	50.50

AN/APQ-97
K-Band

ATCHAFALAYA RIVER BASIN, LOUISIANA

Near Range



HV

0 5 10 Miles

Near Range 0 8 16 Km.

N

HH

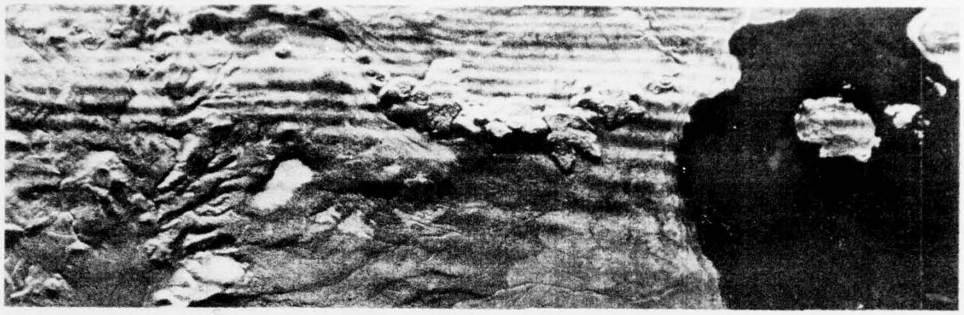
Areas of High Soil Moisture Appear Dark in Near Range of HH (Like) Polarization Imagery. Dry Areas Appear Light in Tone. Soil Moisture Differences are Not Detectable on HV (Cross) Polarized Imagery.

AN/APQ-97
K-Band

MONO CRATERS, CALIFORNIA

Near Range

VV



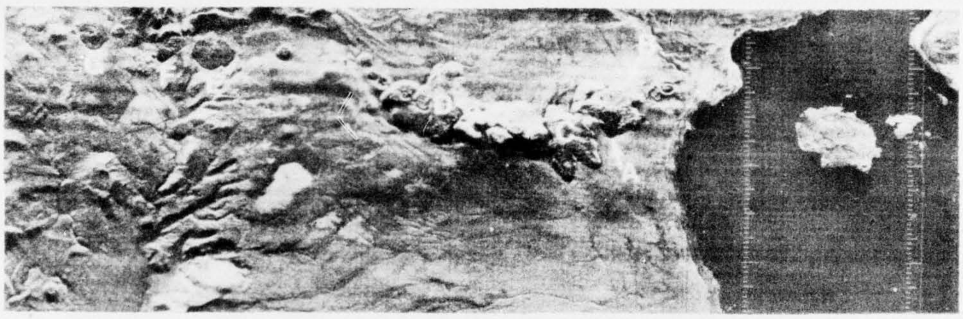
0 5 Miles

0 8 Km.

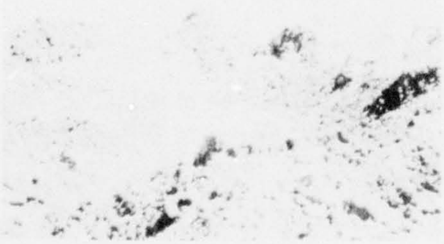
N

Near Range

VH



Flows A, E, F, and G are Blocky Lavas and Have Lower Returns on Cross Polarized (VH) Imagery. Flows D and C are Covered by Ash and Appear the Same on Both Polarizations.



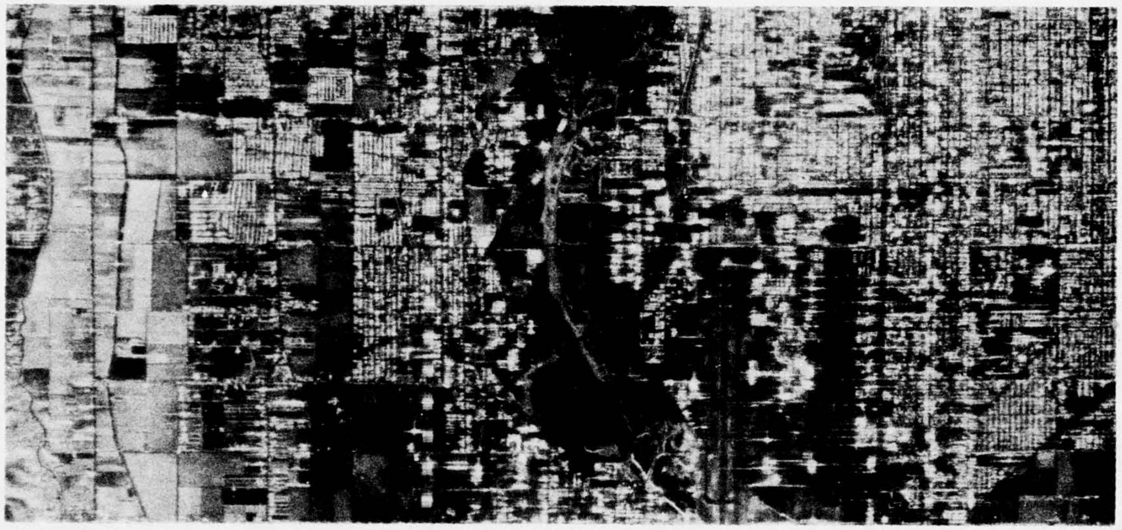
Typical Biocky Lava Flow Which Acts as a Poor Depolarizer.

Typical Ash Covered Flow. A Good Depolarizer.

AN/APQ-97
K-Band

C- VA

LAND USE AND LINES OF COMMUNICATION, PHOENIX, ARIZONA



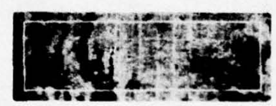
0 1 2 3 Mi.

0 1 2 3 Km.

N ⟶

AN/APQ-152
X-BAND

Look Direction

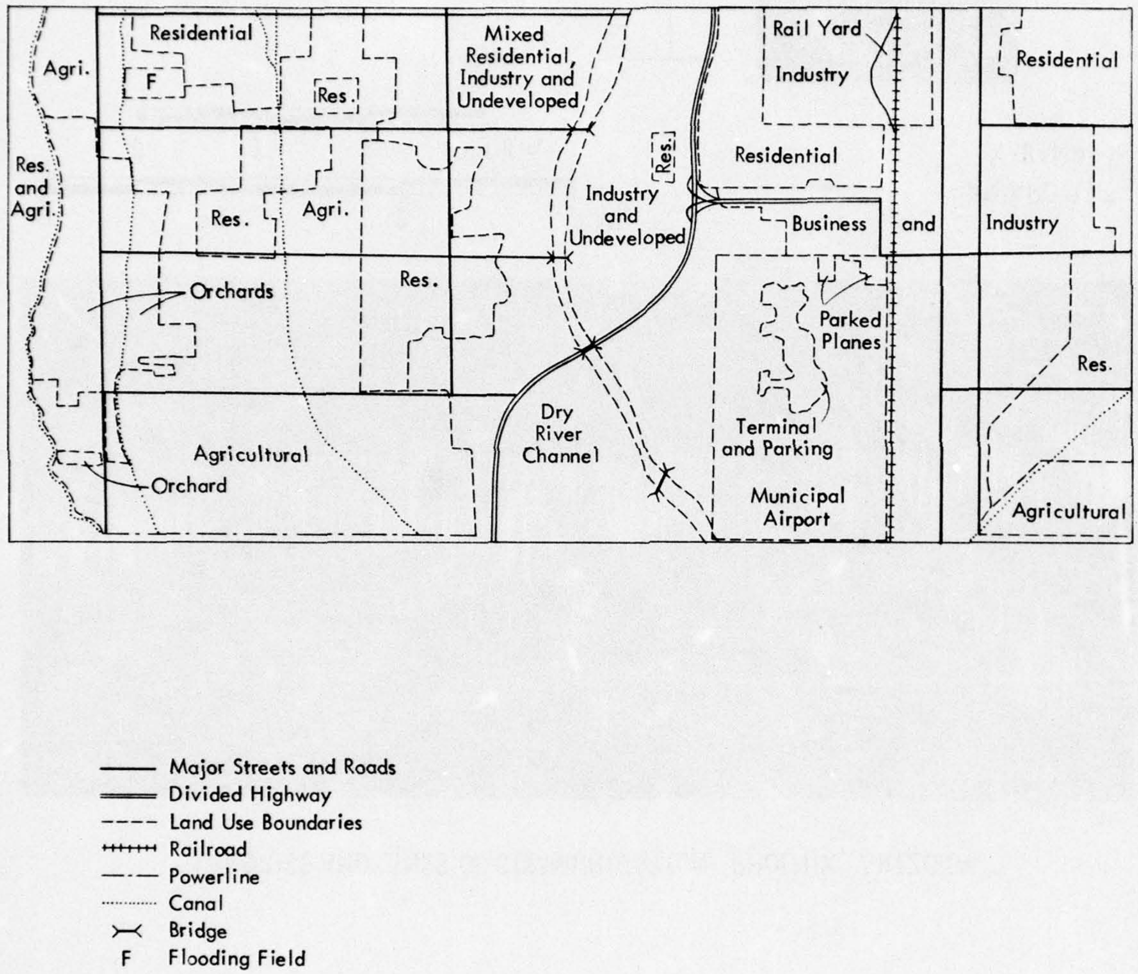


0 5 Mi. 0 8 Km.

N ⟶

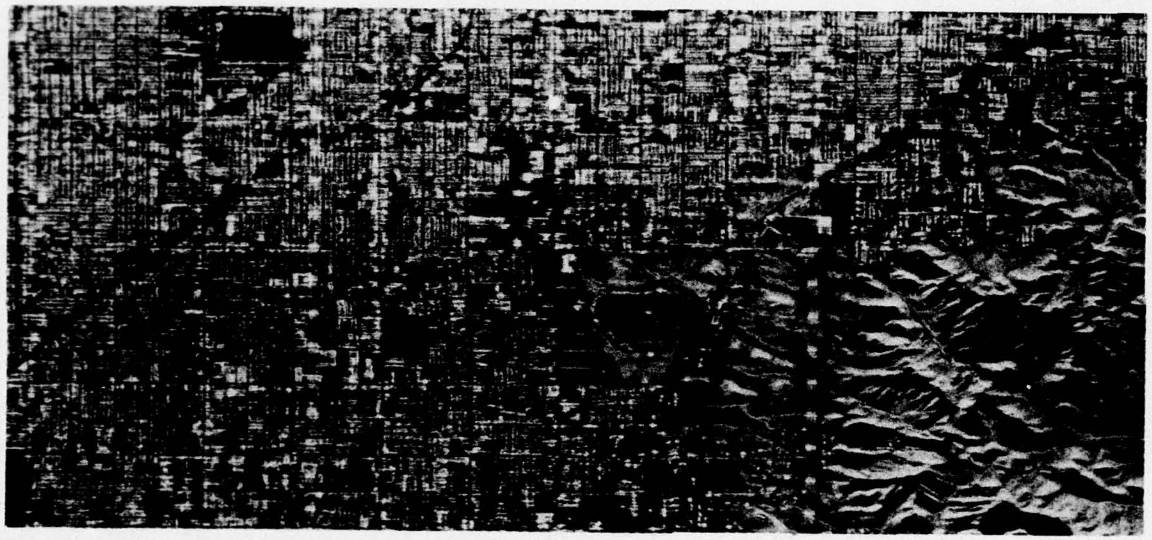
AN/APS-94D
X-Band

C- VA


Agri.
Residential
F
Res.
Mixed Residential, Industry and Undeveloped
Rail Yard
Industry
Residential
Res. and Agri.
Res.
Agri.
Res.
Industry and Undeveloped
Residential
Business
and
Industry
Orchards
Res.
Parked Planes
Res.
Dry River Channel
Terminal and Parking
Agricultural
Orchard
Municipal Airport
Agricultural
Major Streets and Roads
Divided Highway
Land Use Boundaries
Railroad
Powerline
Canal
Bridge
F Flooding Field

C- VB

LAND USE AND LINES OF COMMUNICATION, PHOENIX, ARIZONA



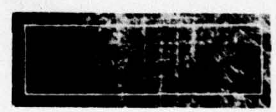
0 1 2 3 Mi.

0 1 2 3 Km.

N →

AN/APQ-152
X-BAND

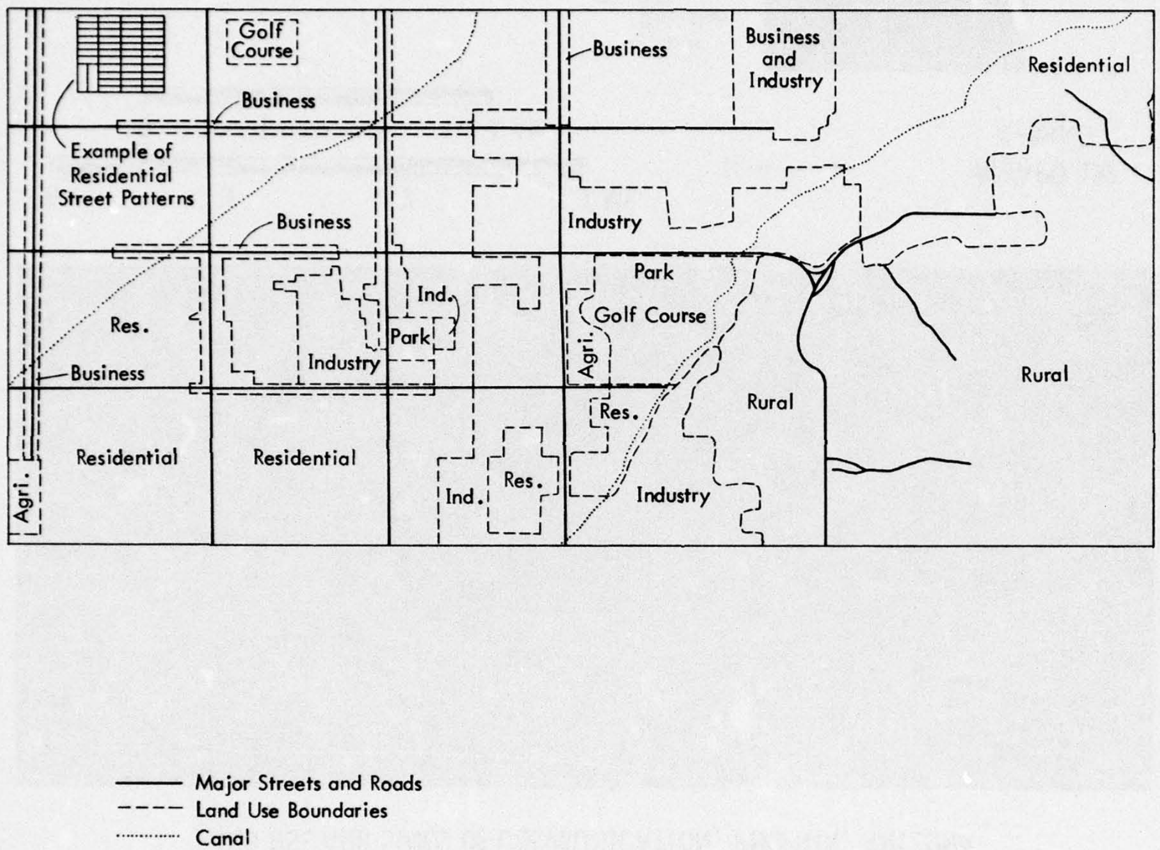
Look Direction



0 5 Mi. 0 8 Km.

N →

AN/APS-94D
X-Band


Golf Course
Business
Business and Industry
Residential
Example of Residential Street Patterns
Business
Industry
Park
Golf Course
Res.
Ind.
Park
Industry
Agri.
Business
Res.
Rural
Rural
Residential
Residential
Ind.
Res.
Industry
Agri.
Major Streets and Roads
Land Use Boundaries
Canal

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technical Transfer Laboratory

Air Pollution Laboratory

Satellite Applications Laboratory